Human Engineering and Safety

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INDEX

Module 1. Introduction to human engineering

Lesson 1. HUMAN FACTORS IN SYSTEM DEVELOPMENT - CONCEPTS OF SYSTEM

1.1 Introduction

The word ERGONOMICS is derived from the two GREEK words: ERGO (means work) and NOMOS (means rules or laws). Thus; Ergonomics is the scientific discipline mainly concerned with understanding of the interaction of humans, and the scientific design profession that applies theory, principles, data and methods to design and improve the work system involving machine or job with human (i.e. operator) as an integral system.

Ergonomics is also sometime called as:

- Man-Machine-Environment System, or
- Human Factors Engineering, or
- Human Engineering.

However; ERGONOMY it is not to be confused with AGRONOMY, which is related to Crop Sciences.

Ergonomics or Man-Machine-Environment System deals with the machine or job, its operator and working environment as a complete system affecting the intended work performance

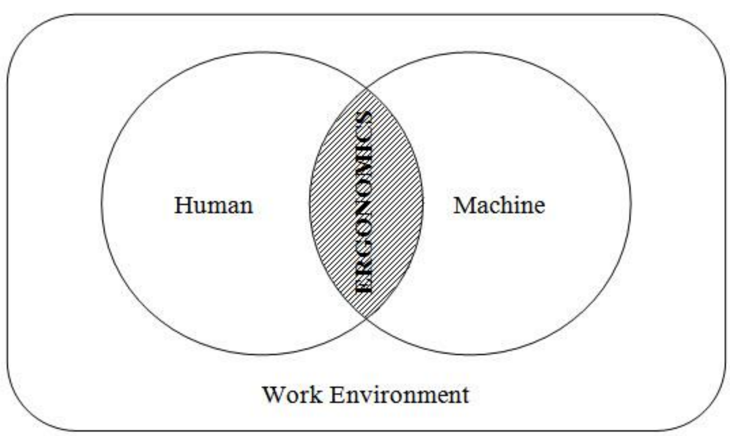


Fig.1.1 Ergonomics as Man-Machine-Environment interaction.

Source: Tayyari and Smith (1997).

The working environment may involve workspace, controls, ambient environment, noise, dust, vibrations, smoke and gases, light, safety concerns, etc. Ergonomics is an application of Medical and Engineering Sciences principles related to human factors in the task concerned

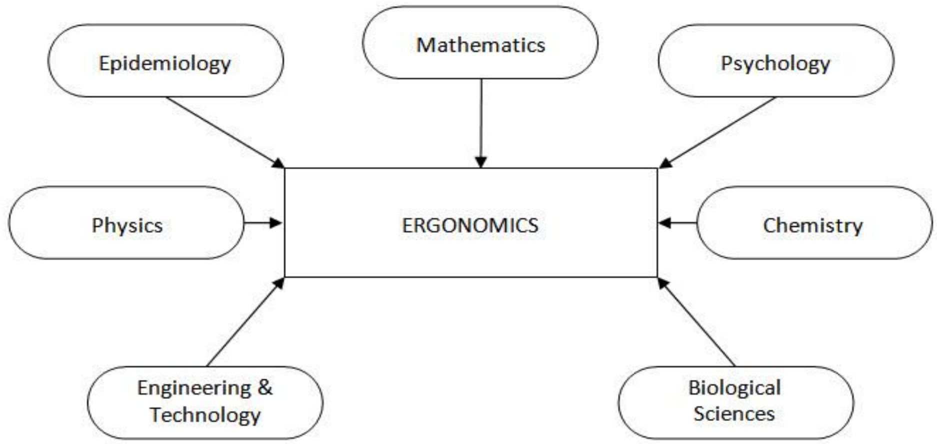


Fig.1.2 Major disciplines contributing to ergonomics.

Source: Tayyari and Smith (1997).

1.2 Definition of ergonomics

- Human-factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable and effective human use (Chapanis, 1996).

- Ergonomics is the scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall performance (International Ergonomics Association, 2000).

- Ergonomics is the design and engineering of human-machine systems for the purpose of enhancing human performance (Dempsey *et al*., 2000).

- Human factor Ergonomics can be defined as the science of design, testing, evaluation and management of human system interaction according to the human-system compatibility requirements (Karwowski, 2005).

- Human factors/ Ergonomics is the scientific discipline concerned with understanding interactions among humans and other elements of a system. It is also a profession that applies theory, principles, data and methods to design in order to optimize human well being and overall system performance (Zink, 2006)

1.3 The operator-machine-environment system approach

The human has a limiting capability as a power of source in comparison to the engine/ machine. However, it has a distinct advantage in terms of its intelligence and decision making as per need. The operator acts as a core of the system. Operator uses his sensory system to perceive the environment, takes decision based upon information available, and finally takes appropriate action for desired output. If the task is new and not well known to operator then the decision making process is very slow. For routine and well known task, decisions are very quick and accurate. Stress is one of the variables that affect operator perception, decision making, and response selection. Many factors including operator's age, training, motivation, etc. affect the success of task performance.

The machine characteristics that are involved in the system are its features, controls, displays, power availability, speed of operation, seat, vibrations, noise, exhaust, visibility, safety features, etc. Workspace, controls layout and display arrangement affects the operator capability to a large extent. For example, a tractor seat is designed for comfort of operator and easy accessibility of controls like brake, steering, gears, clutch, etc.

In the Ergonomics application, "environment" is used to conceptualize the task as well as the context in which it is performed. The ambient environment is only one of the factors covered under this. Noise, vibrations, dust, smoke, field conditions, are some of the other major environmental factors that come into play, thereby affecting task performance.

1.3.1 Relative advantages of man and machine

Man and machine have their distinct comparative advantages over each other. In a system, these advantages can be utilized for their optimum use. Table 1 lists comparison of characteristics of man and machine.

Table 1.1 Relative advantages of men and machine

Characteristic	Machine	Man
Speed	Much faster	Quickest reaction approx. 0.05 second
Power	Consistent at any level, large, constant standard forces.	2.0 hp for about 10 seconds 0.5 hp for few minutes 0.2 hp for continuous work over a day
Consistency	Ideal for: routine; repetition; precision.	Not reliable: should be monitored by machine.
Complex activities	Multi-channel	Single-channel.
Memory	Best for literal reproduction and short term storage	Large store, multiple access. Better for principles and strategies.
Reasoning	Good deductive	Good inductive.
Computation	Fast, accurate, poor at error correction	Slow subject to error. Good at error correction.
Input sensitivity	Some outside human senses, e.g., radioactivity Can be designed to	Wide energy range (10^{12}) and variety of stimuli dealt with by one unit: e.g. eve deals with relative location, movement and colour. Good at pattern detection. Can detect signals against high levels of background noise. Affected by heat, cold, noise and vibration (exceeding known limits)

	be insensitive to extraneous stimuli.	
Overload reliability	Sudden breakdown.	Gradual degradation.
Intelligence	None.	Can deal with unpredicted and unpredictable: can anticipate.
Manipulative abilities	Specific.	Great versatility.

Source: Zander (1973)

1.4 Importance of ergonomics

Ergonomics is the science of designing equipment, the workplace and even the job to fit the worker. Ergonomics is the study of designing equipment and devices that best suited the human body, its movements, and its cognitive abilities. It deals with the physical work environment, tools and technology design, workstation design, job demands and physiological and biomechanical loading on the body. Objective of ergonomics is not only to improve work performance but also to improve human comfort and safety. If ergonomic aspects are not considered, the performance of the system will be poor and the effective working time will be reduced. The goal of ergonomics is to design workplace to conform to the physiological, psychological, and behavioural capabilities of workers. Ergonomics can contribute to the solution of a large number of problems related to safety, health, comfort and efficiency.

1.4.1 Importance of ergonomics in agriculture

In developing countries like India, a large proportion of working population is dependent on agriculture. Also, human workers constitutes as one of the important source of farm power. Besides, human workers also operate animal drawn equipment, tractors, power tillers and other self-propelled machines. The ergonomic aspects during application in agricultural machinery are of great importance as the operator has to operate the machine mostly in field. The physiological as well as psychological fatigue affects performance of the operator. Therefore in agriculture, the application of ergonomics help in increasing the work performance, productivity, efficiency and work duration of farm workers with enhanced comfort and safety.

1.5 System Goals

The goal of ergonomics can be understood in terms of its five main principles, which are:

- Productivity and performance
- Comfort
- Ease of use
- Safety

- Aesthetics

These principles can be broken down into three areas:

- **Physical ergonomics** is concerned with the way the body interacts with the worker's tools (anything from shovels to chairs to personal computers) and their effects on the body such as posture, musculoskeletal disorders, repetitive disorders, workplace layout and workplace health and safety.

- **Cognitive Ergonomics** relates to the way the mind processes information it is presented with and associated motor functions, memory usage, decision-making and other mental workloads. Study of these factors and the interaction between humans and the data presentation can improve everything from the placement of signs, the visibility and recognition and retention of the data.

- **Organizational Ergonomics** is concerned with optimizing the workplace, teamwork, performance assessment and quality management. It includes office design, shift (work hours) management, crew resource management, teamwork, virtual organizations, tele-work, addressing communication, and quality management in the workplace.

Lesson 2. BASIC PROCESS IN SYSTEM DEVELOPMENT

2.1 Introduction

In Ergonomics, each of the human machine and environment has an effect on the complete system. The basic components of each are

A. Human components:

- Sensors/ senses: Through which a human is made aware of its surroundings. Human being has five senses namely right, hearing, touch, taste and smell.
- Information processor: This includes joints, muscles and memory to provide information and feedback and brain to act as information processing system.
- Effectors: The three primary effectors are the hands, feet and voice. However, the whole body more can be regarded as effecter because no physical activity can be carried out without its supporting role.

B. Machine components:

- Displays: These include gauges dials, meters, indicators, etc. and provide information about status and working of machine to the operator.
- Controls: These include components of machine like steering wheel, accelerator, clutch, brake lever etc. through which a human changes and control action of machine.
- Controlled process: This is the basic operation of machine in its local environment as controlled by the human.

C. Local environment:

It is the place and circumstances in which work carried out. It consists of:

- Workspace: It is the three dimensional space in which work is being carried out. It is decided by dimensions of the machine, anthropometry of human and space required for activities of human and machine.
- Physical environment: It means the local environment factors having a bearing on the complete system. It includes noise, vibrations, lights, exhaust, climate etc.
- Work organization: It refers to the organizational structure in which work activity is embedded. It includes role of human and machine in system, organization and other persons of the team upon which the performance depends.

2.2 Objectives of ergonomics:

While planning of the human factors in ergonomics, the objectives and end goal required is to be taken into considerations. These objectives may be one or a combination out of the following:

A. Basic objective:

- To improve system performance
- To reduce errors

To increase safety

B. Objectives concerning users and operators:

- To increase ease of use
- To reduce fatigue and physical stress
- To improve the working environment
- To increase user acceptance
- To improve aesthetic appearance.

C. Objectives concerning reliability and logistic support:

- To improve reliability
- To reduce maintenance
- To reduce labour requirement
- To reduce training requirement

D. Other objectives:

- To improve system efficiency
- To reduce cost of production

2.3 Human Technology interaction

Ergonomics and technology have a specific role to play with each other.

- **The technology** can be defined as entire system of people and organizations, knowledge, process and devices that go into creating and operating technological artifacts. Technology is a product and process involving both science and engineering.

- **Engineering** represents 'design under constraints' of cost, reliability, safety, environmental impact, ease of use, available human and material resources, manufacturability, government regulations, laws and politics.

- **Ergonomics** discovers and applies information about human behavior, abilities, limitations and other characters to the design of tools, machines, systems, tasks jobs and environments for productive, sofa, comfortable and effective human use.

The basic issues and processes covered under Ergonomics for design and development are:

A. Human Characteristics

1. Psychological aspects
2. Physiological and anatomical aspects
3. Group factors
4. Individual differences
5. Psycho physiological state variables
6. Task-related factors

B. Information Presentation and Communication

1. Visual communication
2. Auditory and other communication modalities
3. Choice of communication media
4. Person–machine dialogue mode
5. System feedback
6. Error prevention and recovery
7. Design of documents and procedures
8. User control features
9. Language design
10. Database organization and data retrieval
11. Programming, debugging, editing, and programming aids
12. Software performance and evaluation
13. Software design, maintenance, and reliability

C. Display and Control Design

1. Input devices and controls
2. Visual displays
3. Auditory displays
4. Other modality displays
5. Display and control characteristics

D. Workplace and Equipment Design

1. General workplace design and buildings
2. Workstation design
3. Equipment design

E. Environment

1. Illumination
2. Noise
3. Vibration
4. Whole body movement
5. Climate
6. Altitude, depth, and space
7. Other environmental issues

F. System Characteristics

1. General system features

G. Work Design and Organization

1. Total system design and evaluation
2. Hours of work
3. Job attitudes and job satisfaction
4. Job design
5. Payment systems
6. Selection and screening

7. Training
8. Supervision
9. Use of support
10. Technological and ergonomic change

H. Health and Safety

1. General health and safety
2. Etiology
3. Injuries and illnesses
4. Prevention

I. Social and Economic Impact of the System

1. Trade unions
2. Employment, job security, and job sharing
3. Productivity
4. Women and work
5. Organizational design
6. Education
7. Law
8. Privacy
9. Family and home life
10. Quality of working life
11. Political comment and ethical considerations

J. Methods and Techniques

1. Approaches and methods
2. Techniques
3. Measures

2.4 Factors considered in system development

Some of the important factors considered in design, testing and evaluation of man-machine-environment system are as listed by Dul and Weerdmeester (1993).

A. Anthropometric, biomechanical, and physiological factors:

1. Are the differences in human body size accounted for by the design?
2. Have the right anthropometric tables been used for specific populations?
3. Are the body joints close to neutral positions?
4. Is the manual work performed close to the body?
5. Are any forward-bending or twisted trunk postures involved?
6. Are sudden movements and force exertion present?
7. Is there a variation in worker postures and movements?
8. Is the duration of any continuous muscular effort limited?
9. Are the breaks of sufficient length and spread over the duration of the task?
10. Is the energy consumption for each manual task limited?

B. Factors related to posture (sitting and standing):

1. Is sitting/standing alternated with standing/sitting and walking?
2. Is the work height dependent on the task?
3. Is the height of the worktable adjustable?
4. Are the height of the seat and backrest of the chair adjustable?
5. Is the number of chair adjustment possibilities limited?
6. Have good seating instructions been provided?
7. Is a footrest used where the work height is fixed?
8. Has work above the shoulder or with hands behind the body been avoided?
9. Are excessive reaches avoided?
10. Is there enough room for the legs and feet?
11. Is there a sloping work surface for reading tasks?
12. Have combined sit–stand workplaces been introduced?

13. Are handles of tools bent to allow for working with the straight wrists?

C. Factors related to manual materials handling (lifting, carrying, pushing and pulling loads)

1. Have tasks involving manual displacement of loads been limited?
2. Have optimum lifting conditions been achieved?
3. Is anybody required to lift more than 23 kg?
4. Have lifting tasks been assessed using the NIOSH method?
5. Are handgrips fitted to the loads to be lifted?
6. Is more than one person involved in lifting or carrying tasks?
7. Are there mechanical aids for lifting or carrying available and used?
8. Is the weight of the load carried limited according to recognized guidelines?
9. Is the load held as close to the body as possible?
10. Are pulling and pushing forces limited?
11. Are trolleys fitted with appropriate handles and handgrips?

D. Factors related to the design of tasks and jobs

1. Does the job consist of more than one task?
2. Has a decision been made about allocating tasks between people and machines?
3. Do workers performing the tasks contribute to problem solving?
4. Are difficult and easy tasks performed interchangeably?
5. Can workers decide independently on how the tasks are carried out?
6. Are there sufficient possibilities for communication between workers?
7. Is sufficient information provided to control the tasks assigned?
8. Can the group take part in management decisions?
9. Are shift workers given enough opportunities to recover?

E. Factors Related to Information and Control Tasks

(i) Information

1. Has an appropriate method of displaying information been selected?

2. Is the information presentation as simple as possible?
3. Has the potential confusion between characters been avoided?
4. Has the correct character/letter size been chosen?
5. Have texts with capital letters only been avoided?
6. Have familiar typefaces been chosen?
7. Is the text/background contrast good?
8. Are the diagrams easy to understand?
9. Have the pictograms been used properly?
10. Are sound signals reserved for warning purposes?

(ii) Control

1. Is the sense of touch used for feedback from controls?
2. Are differences between controls distinguishable by touch?
3. Is the location of controls consistent, and is sufficient spacing provided?
4. Have the requirements for control–display compatibility been considered?
5. Is the type of cursor control suitable for the intended task?
6. Is the direction of control movements consistent with human expectations?
7. Are the controls objectives clear from the position of the controls?
8. Are controls within easy reach of female workers?
9. Are labels or symbols identifying controls used properly?
10. Is the use of color in controls design limited?

(iii) Human–computer interaction

1. Is the human–computer dialogue suitable for the intended task?
2. Is the dialogue self-descriptive and easy to control by the user?
3. Does the dialogue conform to the expectations on the part of the user?
4. Is the dialogue error-tolerant and suitable for user learning?
5. Has command language been restricted to experienced users?

6. Have detailed menus been used for users with little knowledge and experience?
7. Is the type of help menu fitted to the level of the user's ability?
8. Has the QWERTY layout been selected for the keyboard?
9. Has a logical layout been chosen for the numerical keypad?
10. Is the number of function keys limited?
11. Have the limitations of speech in human–computer dialogue been considered?
12. Are touch screens used to facilitate operation by inexperienced users?

F. Environmental Factors

(i) Noise and vibration

1. Is the noise level at work below 85 dBA?
2. Is there an adequate separation between workers and source of noise?
3. Is the ceiling used for noise absorption?
4. Are acoustic screens used?
5. Are hearing conservation measures fitted to the user?
6. Is personal monitoring to noise/vibration used?
7. Are the sources of uncomfortable and damaging body vibration recognized?
8. Is the vibration problem being solved at the source?
9. Are machines regularly maintained?
10. Is the transmission of vibration prevented?

(ii) Illumination

1. Is the light intensity for normal activities in the range 200 to 800 lux?
2. Are large brightness differences in the visual field avoided?
3. Are the brightness differences between task area, close surroundings, and wider surroundings limited?
4. Is the information easily legible?
5. Is ambient lighting combined with localized lighting?
6. Are light sources properly screened?

7. Can light reflections, shadows, or flicker from the fluorescent tubes be prevented?

(iii) Climate

1. Are workers able to control the climate themselves?
2. Is the air temperature suited to the physical demands of the task?
3. Is the air prevented from becoming either too dry to too humid?
4. Are drafts prevented?
5. Are the materials/surfaces that have to be touched neither too cold nor too hot?
6. Are the physical demands of the task adjusted to the external climate?
7. Are undesirable hot and cold radiation prevented?
8. Is the time spent in hot or cold environments limited?
9. Is special clothing used when spending long periods in hot or cold environments?

Module 2. Human performance and responses

Lesson 3. HUMAN PERFORMANCE AND PERFORMANCE RELIABILITY

3.1 Human performance

The ergonomic aspects during application in agricultural machinery are of great importance as the operator has to operate the machine in field. The physiological as well as psychological fatigue affects performance of the operator and: hence, man-machine-environment system. There are many factors acting as stress on the operator during the work. These stresses may be due to workload, immobilization for longer duration work, ambient temperature, relative humidity, vibrations, noise, dust, smoke, exhaust gases, etc. A feeling of chance of accident during work, space confinement, overload of information to be handled, etc. results in psychological fatigue. During the ergonomic studies, these stresses can be measured in terms of strain on the operator. The most important among physiological strains are related to heart activity, respiration, discomfort, muscular fatigue, etc. During ergonomical studies, stress on eyes, hearing loss, errors, speed of work, work performance are some of the commonly used parameters for measurement of psychological/ mental strain.

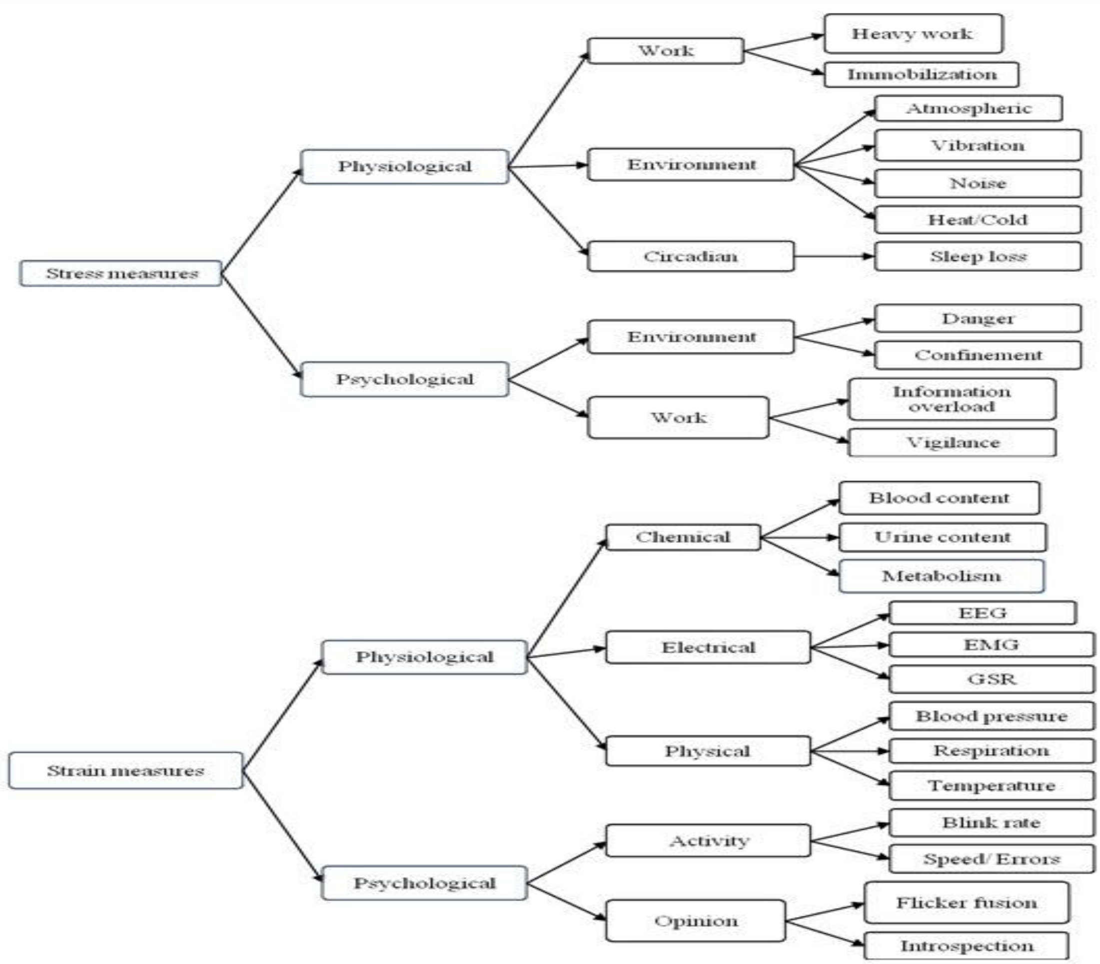


Fig.3.1. Human stresses and strains in ergonomic studies

During ergonomic intervention, subjects (operators or workers) are an integral part of the man-machine-environment system. The subjects must be medically fit and represent real user population in operation of the selected machinery.

3.1.1 Physiological factors for measurements

Physical activities stimulate certain physiological responses in human beings. These responses provide basis for human energy expenditure and fatigue. The physiological measurements are made generally in terms of heart and respiration activities.

3.1.1.1 Heart rate

Heart rate (HR) is the most reliable dependent parameter in ergonomic studies. This is because the heart rate has a direct and linear relationship with the human workload and stress. A starting period of 2-3 minutes is sufficient for heart/pulse rate to stabilize depending upon nature of exercise. Also, care has to be taken so that the operator is not subjected to workload leading to heart rate more than HR_{max} i.e. the upper limit of heart rate allowed during an activity.

Here,

HR_{max} (beats/min) = 220 – Age (years) ------ (1)

3.1.1.2 Respiration rate

The respiration is another basic variable in work physiology as it is linearly related to the workload. It is measured in terms of rate of volume of air inhaled or air exhaled or oxygen intake (VO_2) or respiration rate. The greater the demands made on the muscle by the physical activities, the more air or oxygen is inhaled. The human energy expenditure (kilo Joule, kJ) is computed by multiplying the oxygen consumption (litres, l) with the calorific value of oxygen (20.88 kJ/l). The human workload has been categorized between light work and extremely heavy work depending upon heart rate or oxygen consumption (Table.1). Another criterion for measurement of human performance is Relative Load (RL) which is expressed as percentage of maximum aerobic power (VO_{2max}); where, VO_{2max} is volume of oxygen intake corresponding to HR_{max} calculated from established relation between VO_2 and HR of an individual through subject calibration on treadmill or bicycle ergometer. Daily (8 hours) physical activity involving 35% of VO_{2max} might be considered as an acceptable workload (AWL) for Indian workers.

Table 1. Limits of physiological responses and work category.

S. No.	Work category	Physiological response	
		Oxygen consumption (l/min)	Heart rate (beats/min)
1	Light work	< 0.5	Up to 90
2	Moderate work	0.5 - 1.0	90-110

3	Heavy work	1.0-1.5	110-130
4	Very Heavy work	1.5-2.0	130-150
5	Extremely heavy work	> 2.0	150-170

Source: Astrand and Rodahl (1986)

3.1.1.3 Discomfort rating

Body posture is one of the major factor which causes muscular fatigue and discomfort in the body. Uncomfortable body posture in different activities reduces work efficiency, capacity and safety of operator. The effect due to working posture can be measured in terms of overall discomfort rate and body part discomfort rate techniques. Table-2 gives the pain intensity score as measure of overall discomfort rate. The same score can be used for measurement of body parts discomfort rating.

Table 2. Pain intensity score as a measure of overall discomfort rating (ODR).

Subjective feeling	ODR Score	Subjective feeling	ODR Score
Comfortable	0	Moderately painful	4
Uncomfortable	1	Highly painful	5-6
Pain starts	2	Very highly painful	7-9
Slightly painful	3	Extremely painful	10

Source: Borg (1982)

3.1.2 Psychological factors for measurements

Certain working operations need overload of information, vigilance, danger or work performance accuracy. In such conditions, there is a higher load on sensory/neuro organs of the human body. Such situations cause higher stress on eyes, hearing system, brain activity, etc. resulting in poor work performance, more errors, more missing, lesser endurance, etc. These situations sometimes may lead to headache, drowsiness and even accident. These stresses can be measured in terms of reaction time measurement technique, blink rate, flicker fusion, critical hearing threshold level, speed & errors in work performance, etc.

3.2 Performance reliability

Performance reliability refers to quantitative values that characterize the dependability of system or components performance. The reliability of system can be defined in many ways:

- Reliability is probability of a system performing its intended function over a given period of time under the operating condition encountered.
- Reliability is the probability that a system will operate without failure for a given period of time under given operating conditions.

- Reliability is mean operating time between two successive failures.
- Reliability is integral of distribution of probabilities of failure free operation.

A state of fault is denoted by failure. It may be any of the three types:

1. Completely un-operational.
2. Operational but intended function is not performed satisfactory.
3. Serious deterioration in quality of its operation or unsafe operation.

Reliability in terms of probability of successful performance is applicable when the performance consists of discrete events. However; reliability in terms of mean time to failure is applicable in case of time for successful continuous performance before failure. If a system includes two or more components (machine or human or both), then reliability of the composite system will depend upon reliability of individual components and how they are combined within the system. Components can be combined within the system either in series or parallel or a complex system of series and parallel arrangement.

3.2.1 Components in series

System consists of number of components connected in series i.e. system operates if all are OK and system fails if any one of components fails. So weakest link i.e. component having lowest possibility of survival is the most critical one

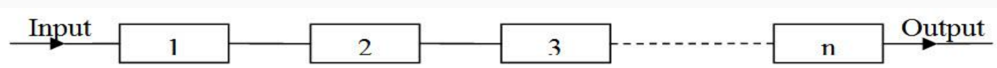


Fig.3.2 Components in series.

Here, reliability of system (R_s) is product of reliability of each and every individual component connected in series.

Thus; $R_s = R_1 \times R_2 \times R_3 \times \ldots\ldots\ldots R_n$ ------ (2)

3.2.2 Components in parallel

Parallel system involves more cost, but is more reliable because if any of the components in parallel is functioning, that means system is in working order. The system fails only if each and every component connected in parallel fails simultaneously. Reliability of system (R_s) is determined after calculating probability of failure of the system (Q_s)

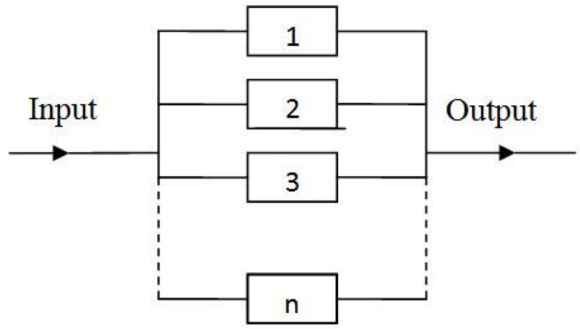


Fig 3.3 Components in parallel.

Thus; $R_s = 1 – Q_s$ ------ (3)

Where, $Q_s = Q_1 \times Q_2 \times Q_3 \times \ldots\ldots\ldots Q_n$ ------ (4)

Here, Q_i is failure probability of i^{th} component.

Lesson 4. INFORMATION INPUT PROCESSES

4.1 Information input process

"Information" is the transfer of energy that has meaningful implications in any given situation; e.g. a driver communicating with his tractor through displays and controls. The input to the operator is the information received through the sense organs. Our sensory mechanisms are sensitive to certain stimuli, which convey meaning to us. The stimuli are various forms of energy, such as light, sound, heat, and mechanical pressure. Information from the original source may be direct (e.g. a visual signal of undulated field), or indirect (e.g. quantity of fuel in tractor tank through fuel meter on display board, change in sound of tractor engine). The humans are continually bombarded with stimuli from our immediate environment, these stimuli consisting of various forms of energy to which our senses organs are sensitive. The interpretation of such stimuli (i.e. information they convey) is generally a function of our learned association. The processing of information include the sense which acts as primary input and gives signal to brain. The human perceptual sensors are (Table 1):

Table 1 Human sensors and associated input signals

Human sensors	Associated input
Eyes	Visual input
Ears	Acoustic signals
Skin	Touch/ Warm
Nose	Smell
Tongue	Taste

It is noticed that usually multiple senses operate at the same time. For example, driver of a tractor uses eyes, ears and skin or all of them at same time.

4.1.1 Information processing system

How humans perceive and process information must be taken into account in order to design interfaces that can be learned and used efficiently. In all human-system interactions, the user must perceive information, process information, and make decisions based on that information, leading to responses and actions. For example, the human eye receives visual information and codes information into electric-neural activity which is fed back to the brain where it is stored and decoded. This information can be used by other parts of the brain relating to mental activities such as memory, perception and attention

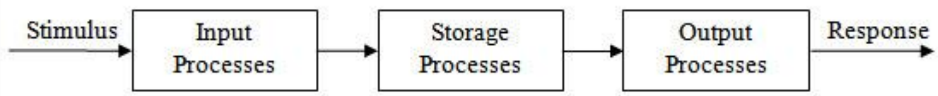


Fig 4.1 Information processing system

The output (i.e. behavior or action) might be, for example, to safely drive a tractor on the road.

Information processing system consists of a series of stages, which represent stages of processing. Arrows indicate the flow of information from one stage to the next

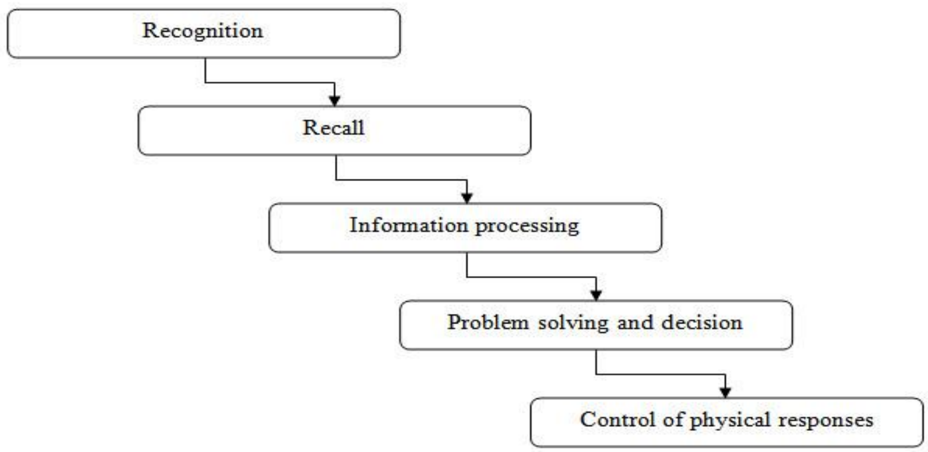


Fig. 4.2. Information retrieval and processing

1. **Input** processes are concerned with the analysis of the stimuli.
2. **Storage** processes cover everything that happens to stimuli internally in the brain and can include coding and manipulation of the stimuli. Information stored can be a short term or a long term memory.
3. **Output** processes are responsible for preparing an appropriate response to a stimulus.

4.1.2 Measurement of information

Information is measured in bits (binary unit). A bit is defined as the amount of information obtained from one of two equally likely alternatives specified. When various alternatives are equally probable, the amount of information is given by formula:

$$H = \log_2 n \qquad \text{-------- (1)}$$

Where, H is amount of information in bits, and n is number of equally probable alternatives.

If n is 2 then H is logarithm of 2 to the base 2, which is 1. For example, if there are four lights on a panel and only one of them may be on at a time, then we have two bits of information.

Equation 1 can be written in terms of probability of each alternative, where probability is the reciprocal of n. Therefore;

$$H = \log_2 1/p \qquad \text{-------- (2)}$$

4.1.3 Stimulus characteristics

The stimulus inputs that human receive via any sensory modality (vision, audition etc.) differ in terms of their characteristics. For example, visual characteristics include shape, configuration, size, position, color, etc. The auditory characteristics include sound pressure level, frequency, duration, continuous/intermittent signal, etc.

4.1.4 Displays for information input

Displays can be either dynamic or static. Dynamic displays are continually changing or are subject to change with time, e.g. temperature or pressure gauge, fuel gauge, ampere meter, RPM meter, speedometer, monitors and displays, TV and radio signal, etc. Static displays remain fixed over time, e.g. signs, charts, graphs, labels etc. There is a need of presenting information to people by use of displays in such a manner so that usefulness of information under given conditions is enhanced affectively.

4.1.5 Information presented by displays

Major types of information presented by displays are described below.

1. Quantitative information: Such displays present quantitative value of some variable like temperature, pressure, speed, etc.

2. Qualitative information: Such displays provide approximate value, trend, rate or direction of change. E.g. ampere meter of chargeable battery, RPM meter showing approximate value, etc.

3. Status information: Such displays present condition or status of a system. E.g. ON-OFF indicators, stop-caution-go lights, indicator for reverse gear, warning indicators, battery status indicator, etc.

4. Warning and signal information: Such displays indicate emergency or unsafe conditions or absence of some object/ conditions. E.g. aircraft or lighthouse bacons, reverse light indicators, turning indicators, brake light indicators, signal for low/high beam light, seat belt signal, door open signal, fuel refill indicator, etc.

5. Representational information: Such displays provide pictorial or graphic representation of objects areas or other configurations. E.g. movies, photographs, maps, charts, diagrams, graphs, door open signal, seat belt indicator, heart beat shown on heart rate monitor, etc.

6. Identification information: Such displays are used to identify a particular condition, situation or object. E.g. sign boards on the roads, traffic lights, color coded signals, etc.

7. Alphanumeric and symbolic information: Such displays provide audible, numerical or related coded information. E.g. signs, labels, placards, instructions, music notes, printed and typed material including Braille, etc.

8. Time phased information: Such displays give pulsed for time phased signals. E.g. blinking lights, Morse code, intermittent beeps, etc.

4.1.6. Selection of sensory modality

Selection or designing of displays for transmission of required information plays very important role in certain situations. The decision may depend upon a number of considerations as given in Table 1.

Table 1. When to use the auditory or visual form of presentation

Use auditory presentation, if:	Use visual presentation, if:
The message is simple	The message is complex
The message is short	The message is long
The message is not be referred to later	The message will be referred to later
The message deals with events in time	The message deals with location in space
The message calls for immediate action	The message does not call for immediate action
The visual system of the person is overburdened	The auditory system of the person is overburdened
The receiving location is too bright or dark-adaption integrity is necessary	The receiving location is too noisy
The person's job requires him to move about continually.	The person's job allow him to remain in one position

Source: Sanders and McCormick (1993)

Lesson 5. MAJOR TYPES AND USES OF DISPLAYS

5.1. Classification of displays

Displays provide useful and required information in a conveniently presentable form. Displays can be broadly classified under three categories:

1. Visual displays
2. Auditory displays
3. Tactual displays

5.1.1. Visual displays

They are the most common in use and involve visual capabilities and skills of users. The commonly used types of visual displays are discussed here.

5.1.1.1. Quantitative visual displays

These displays provide information about quantitative value and some variable, which may be a dynamic variable such as temperature or speed, or a static variable such as measurement of length with a ruler. Such displays have units written alongwith quantity of variable. There are three basic types of dynamic quantitative visual displays

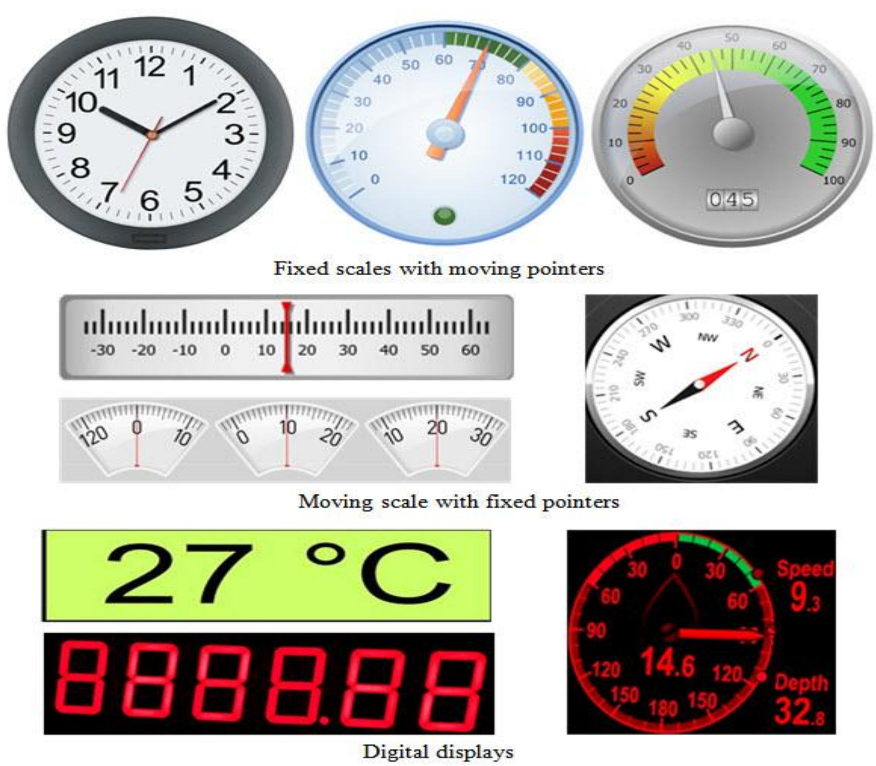


Fig.5.1 Quantitative visual displays

1. Fixed scales with moving pointers
2. Moving scales with fixed pointers
3. Digital displays or counters

Fixed scale with moving pointer type displays are mostly preferred; however, for long scales displays having circular or tape type moving scales are preferred. Digital displays used if values remain long enough to read.

5.1.1.2. Qualitative visual displays

Such displays provide approximate value, trend, rate or direction of change. Quantitative data is used as a basis for qualitative reading in at least three different ways:

1. To convey information about status or condition of variable falling within limited number of predetermined ranges. E.g. temperature gauge to determine if engine whether engine is cold/ normal/hot

Fig.5.2 Qualitative visual displays

2. To maintain roughly a desirable range of values. E.g. speedometer showing range of speed between 0-50 mph for safer control.
3. To observe trends, rate of change, etc. E.g. engine RPM meter.

5.1.1.3. Status indicators

They provide approximate information as an indication of status of a system or component. E.g. temperatures gauge to dip it if the engine is cold/normal/hot. Other examples include ON/OFF indicator, traffic light on roads etc (Fig.5.3). If a quantitative instrument is to be used only for check-reading purpose, status indicator should be preferred.

5.1.1.4. Signal and warning lights

Flashing and steady state lights are used for various purposes viz. indications of lower/upper beams of lights, warning lights for low-battery, low-fuel, seat-belt not used, door-open, engine-oil level low, low brake-oil, hand-brake ON, reverse gear engaged, beacons, etc (Fig.5.4). Detection of signals and warning lights may depend upon size, luminance, color, background, exposure time, and flash rate.

5.1.1.5. Representational display

Representational displays may be pictorial i.e. intended to reproduce an object/scene or may be symbolic/illustrative. The purpose of such display is to convey a visual impression that requires little interpretation. For example: aircraft position display, GPS for road map, charts and graphs, etc (Fig. 5.5).

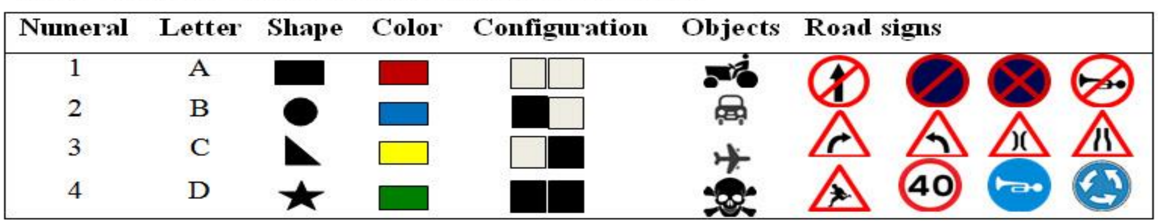
5.1.1.6. Alphanumeric and related displays

The effectiveness of such displays depends upon various factors like typography, content, selection of words, color, background, contrast, illumination, and writing styles. The typography of alphanumeric information includes stroke width, aspect ratio, font type, font size, spacing of characters, spacing between lines, margins, color, etc. The communication of message by such displays depends upon visibility, legibility, and readability (Fig. 5.6).

5.1.1.7. Visual codes symbol and signs

In our daily life we use a variety of visual codes symbols and signs which convey their intended meaning. They includes numerals, letters, geometrical shapes, colors, configurations, symbolic shapes representing various objects and messages (Table 5.1).

Table 5.1. Some examples of visual symbols and signs



5. 2. Auditory displays:

The auditory displays involve sound as a signal. In a human-machine interface, the frequency and intensity/amplitude are two primary attributes of sound. In general, the human ear is sensitive to sound waves having frequency range between 20-20,000 Hertz (Hz). Intensity of sound or sound pressure level is generally measured in *decibel* (dB). A *decibel* is one-tenth of a *bel* (named after Alexander Graham Bell) and is expressed as a ratio on logarithmic scale. The Sound pressure level (SPL), measured in *decibels*, can be written as:

$$SPL = 20 \log P_o/P_r \qquad \text{------ (1)}$$

Where, P_o is root mean square (rms) acoustic pressure at point of consideration, and P_r is reference pressure (20 μPa).

Circumstances under which auditory displays are preferred:

1. When the origin of a signal itself is a sound.
2. When the message is simple and short.
3. When the message doesn't need to be referred afterwards.

4. When the message deals with events in time.
5. When the message calls for immediate action.
6. When the visual display system is overloaded.
7. When illumination limits use of vision.
8. When the operator moves away from visual display.

The commonly used auditory displays are radio signals (dot-dash system) or warning and alarm signals. The commonly used devices for warning and alarm signals are horn, whistle, siren, bell, buzzer, chimes, etc.

5.3. Tactual display:

Tactual displays use cutaneous (skin or somesthetic) senses. Such displays utilize a qualitative or comparative sensation of thermal or mechanical or chemical or electrical stimulus. Thus its use is only to a very limited extent or under special conditions. Braille is particularly important for people who are visually impaired. The Braille display and textual maps are good examples of tactual displays. Another use of tactual senses control knobs. The coding of such devices for tactual identification includes their shape, texture and size. Vibrator of a cell phone that uses a mechanical stimulus is another example of our daily life.

Lesson 6. SPEECH COMMUNICATION

6.1. Introduction

Messages are communicated by one to others either in written or spoken form and; thereby, involves visual and auditory senses. Speech communication uses various speech sounds and audio codes. Communication of messages involves at least two or more persons. To a talker, speech is an 'output'; and, to listener(s) is an 'input'. Mostly, speech communication is normal in its transmission and reception. However, it can be adversely affected by noise like that of an engine or tractor nearby, or by the communication aid like that of sound-speakers, radio, telephone, etc. Such concerns need due care; especially, if the message to be communicated is a critical one.

6.2. Terminology

- **Phonemes:** Speech consists of speech sounds called phonemes.
- **Articulators:** The phonemes are generated by articulators viz. the lips, tongue, teeth and palate. The articulators interact to interrupt or constrict the breath stream.
- **Articulation:** Articulation is the process to form possible phonemes.

6.3. Characteristics of speech

When any speech phonemes or sound is generated, it produces speech waves i.e. variation in air pressure. A waveform represents variation in air pressure over time. A spectrum represents combinations of frequency and intensity of speech sound. A combination of many individual speech sounds can be represented by an overall or a continuous spectrum.

Intensity of speech: The average intensity of individual phonemes varies. Vowels have more speech power than consonants. Intensity is more if spoken loudly as compared to soft speaking.

Frequency of speech: Each phoneme has its unique spectrum of several frequencies which may differ with each individual. The pitch and loudness changes with change in circumstances like quiet conversation, yelling, warning to others, etc.

6.4. Components of speech communication

Speech communication has four components:

- The message
- The talker
- The transmission system and environment, and

- The receiver.

Each of these components has to be looked into to improve the intelligibility of speech communication.

6.4.1. The message

Under adverse conditions, such as noise, the speech messages are likely to get degraded while reaching to others. Hence, the messages should be constructed in such a way so as to have high probability of reaching without any distortion.

6.4.1.1. The vocabulary used

If a word is picked up randomly from a dictionary and communicated, then the listener might take it wrongly if it is unknown or lesser known or one out of a long list of words to him/her. However, if it is a known or expected or selected from a very limited list of vocabulary of words, then probability of guessing the right one by the listener is comparatively very high even under adverse environmental/transmission conditions.

6.4.1.2. Context of the message

Like the vocabulary used, it is also related similarly to the message. Thus; size of the context matters to correctly assume missing word in a sentence. If a known sentence is spoken, then missed word in it can be correctly guessed. Sentences are more intelligible than isolated words, and isolated words in turn are more intelligible than separate syllables.

6.4.1.3. Phonetic aspects of message components

Some speech words have high levels of speech power and; therefore, have a better chance of getting through correctly under adverse conditions.

6.4.2. The talker

Intelligibility of speech depends partly on the characteristics of talker's speaking voice. Each and every individual talker, if asked to read same context, has his own voice quality, word's pronunciation, speed of talk, clarity of words and accent. TV and radio anchors have a high quality and clarity of speech while communicating.

6.4.3. The transmission system and environment

Commonly used transmission system for speech communication are mike & speakers, telephones, radio, television, video clippings, audio-clippings, face to face talking, etc. These transmission systems can produce a variety of forms of distortions, such as:

1. Frequency distortion

2. Filtering

3. Amplitude distortion

4. Modification of time scale, etc.

Their knowledge can be useful for making decision about selection of communication equipment.

6.4.3.1. Effect of filters

Filters block out certain frequencies and permit only the remaining frequencies. Filtering can be unintentional or intentional in design of equipment. A 'low pass filter' eliminates frequencies above some level; whereas, a 'high pass filter' eliminates frequencies below some level. Cut off is not precisely at a specific frequency but tapers-off over a range of frequencies.

6.4.3.2. Effect of amplitude distortion

Amplitude of speech is distorted when a signal passes through a non-linear circuit. 'Peak clipping' clips off the peaks of sound waves and retains center form

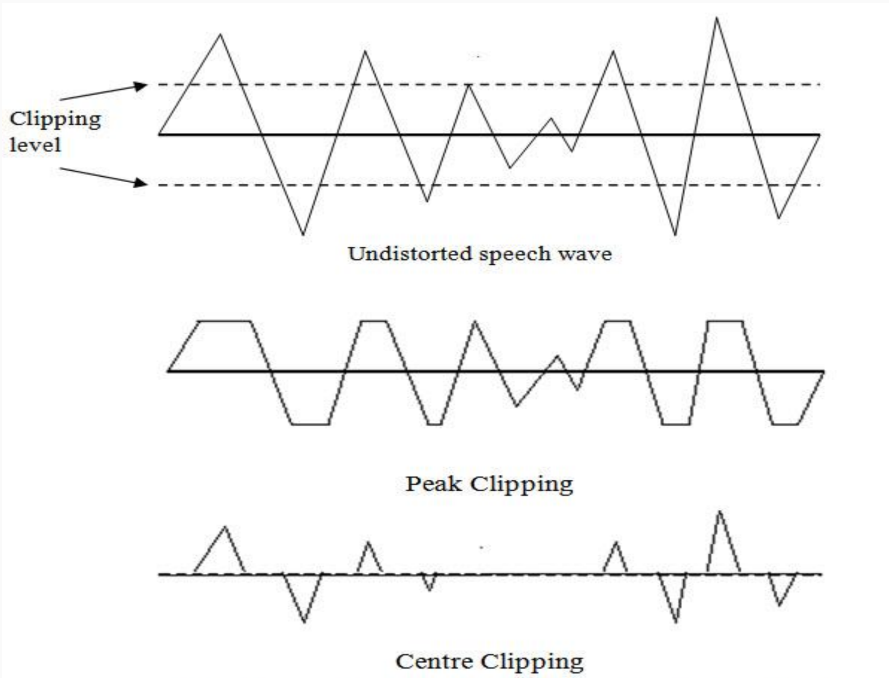


Fig.6.1. An illustration of undistorted and clipped speech wave.

Peak clipping does not cause major degradation of intelligibility as it clips off mainly vowels which have generally more speech power. 'Center clipping' clips off centre of sound waves and retains peaks. It causes major degradation of sound as it clip off mainly consonants which have generally less power.

6.4.3.3. Effect of noise

Noise is taken as unpleasant or undesired sounds from sources other than we want to listen. Even if we consider a most silenced environment, ambient noise is still present and can be measured by a sound pressure level meter. Some in-line noise in communication equipment also distorts speech. Distance of a source of noise is also important as it is inversely proportional to the sound pressure level to the listener.

6.4.3.4. Effect of reverberation

Reverberation is the effect of noise bouncing back and forth from the walls, ceiling and floor of an enclosed room. The reverberation effects round quality in big hall-rooms like auditoriums. The relationship between reduction in intelligibility and reverberation time (i.e. time it takes the noise to die down) is linear

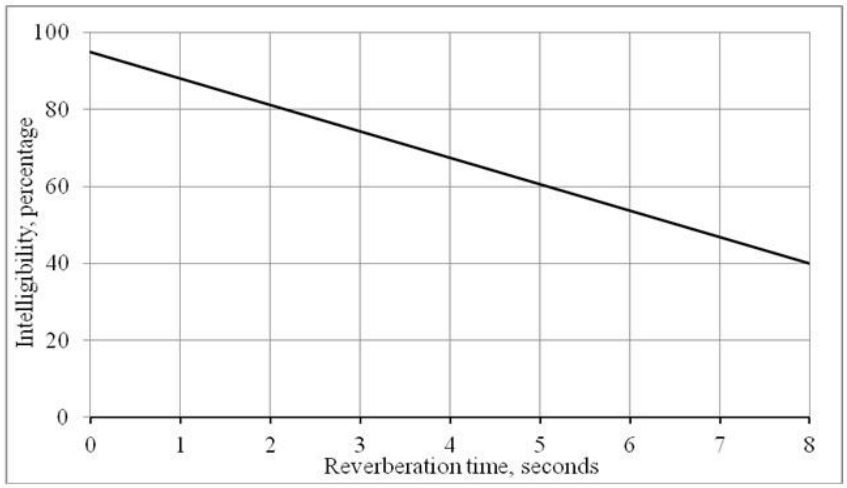


Fig.6.2. Intelligibility of speech in relation to reverberation time.

6.4.3.5. Effect of earplugs

Earplugs are a part of transmission system as they intervene between the environment and the receiver. Earplugs are aid tools to increase intelligibility of speech under high noise levels. Earplugs worn by staff at airports cut off external noise in a major proportion. Small sized earphones placed near to ears reduce chance of ambient noise to distort the message from source.

6.4.4. The receiver

It is a last link in speech communication chain. For receiving speech messages under noisy conditions, receiver should have qualities, like

- Normal hearing ability
- Training in receiving communications
- Durability to withstand stresses of situation
- Concentration to focus on one of several conflicting stimuli.

Whenever possible, speech should be communicated under favorable conditions, without interfering with noise. Many a times, it is not possible to reduce noise e.g. noise of tractor engine, traffic, machines in a manufacturing unit, etc. Under such circumstances, other elements of communications system may be involved.

Module 3. Working environment and work space design

Lesson 7. BIOMECHANICS

7.1 Biomechanics:

Biomechanics is the study of conditions, which deals with the internal and external forces and their effects on human body. This is the study of two states of conditions viz. statics and dynamics under which subject is in motion or stay in rest. Statics condition deals largely with the conditions under which the subject remains at rest whereas dynamics condition deals largely with the conditions under which the subject moves.

7.2 Biomechanics of Human movement:

There are various tasks which require movement of the whole body, while exerting a force. Such movements can cause mechanical stresses resulting to body aches and pains. Movements can also be stressful in the energetic sense for the muscles, lungs and heart. Fundamentally there are two different approaches to studying the biomechanics of human movement: forward dynamics and inverse dynamics. Either can be used to determine joint kinetics e.g., estimate joint moments during movements.

7.2.1. Forward Dynamics

To study of human movements, the input to the system is the neural command is forward dynamics which specifies the level of activation to the muscles. The neural command can be estimated from electromyograms (EMGs) or by optimization models derived by Zajac, 1989; Pandy and Zajac, 1991. In each musculotendonous unit, the force contributes toward the total moment about the joint. Since muscle force is dependent upon muscle length, there is feedback between joint angle and musculotendon dynamics. The moment arms of muscles are not constant values, it change as a function of joint angles.

7.2.3. Inverse Dynamics

The Inverse dynamics approaches the problem from the opposite end by measuring position and the external forces acting on the body. In gait analysis, for example, the position of tracking targets attached to the segments can be recorded by using a camera-based system and the external forces can be recorded by using a force platform.

7.3 Biomechanics of Motion:

The biomechanics of motion deals with the various aspects of the physical movements of the body members. The operation of the body members can be characterized in terms of estimating the joint moments during movements (Table7.1). The bones connected at their joints, in combination with their associated muscles, of serve as lever.

Table. 7.1. Biomechanics terminology and their description

S.No.	Terminology	Description
1.	Anterior	Anterior refers to front side, nearer the front surface of the body
2.	Posterior	Posterior refers to back side, nearer the back surface of the body
3.	Superior	Superior refers to the upper or higher part of body, or nearer he crown of the head
4.	Inferior	Inferior refers to the lower part of the body, or nearer the soles of the feet
5.	Medial	Medial is nearer the median plane of the body (or body part) which divides the body (or body part) into right and left halves
6.	Lateral	Lateral refers to the farther from the median plane
7.	Proximal	Proximal is the end of a body member nearer the body
8.	Distal	Distal is the end of a body segment farther from the body
9.	Palmar or volar	Palmar/ volar refers to the anterior surface of the hand or forearm
10.	Dorsal	Dorsal pertaining to back side, nearer the back to the hand, forearm and foot (dorsal surface of the hand, opposite of palmar)
11.	Planter	Planter refers to the sole of the foot

7.4 Range of Movements:

Movement is defined by reference to a plane or axis. As Shown in Fig. 7.1. there are three planes and four axis which are described as under:

Planes of movements

Sagittal Plane - a vertical plane which passes from front to rear dividing the body into right and left sections

Frontal or lateral Plane - which passes from side to side at right angles to the sagittal plane which divide the body into a front and back section, It is any vertical plane perpendicular to the median plane which divides the body into anterior (front) and posterior (back) portion.

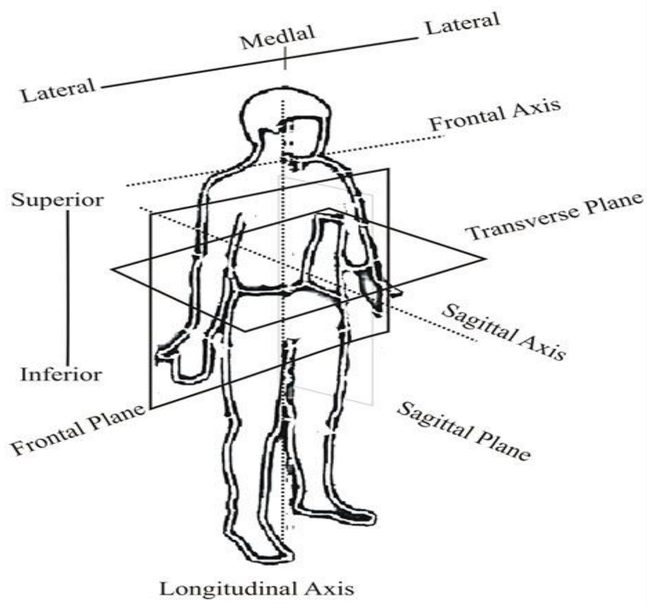


Fig. 7.1. Reference Planes

Transverse or horizontal Plane - a horizontal plane which divides the body into superior (upper) and inferior (lower) parts.

Axis of movements

Frontal Axis - passes from side to side at right angles to the sagittal plane

Sagittal or Transverse Axis - passes horizontally from front to rear lying at right angles to the frontal plane

Longitudinal or Vertical Axis - passes from head to foot at right angles to the transverse plane.

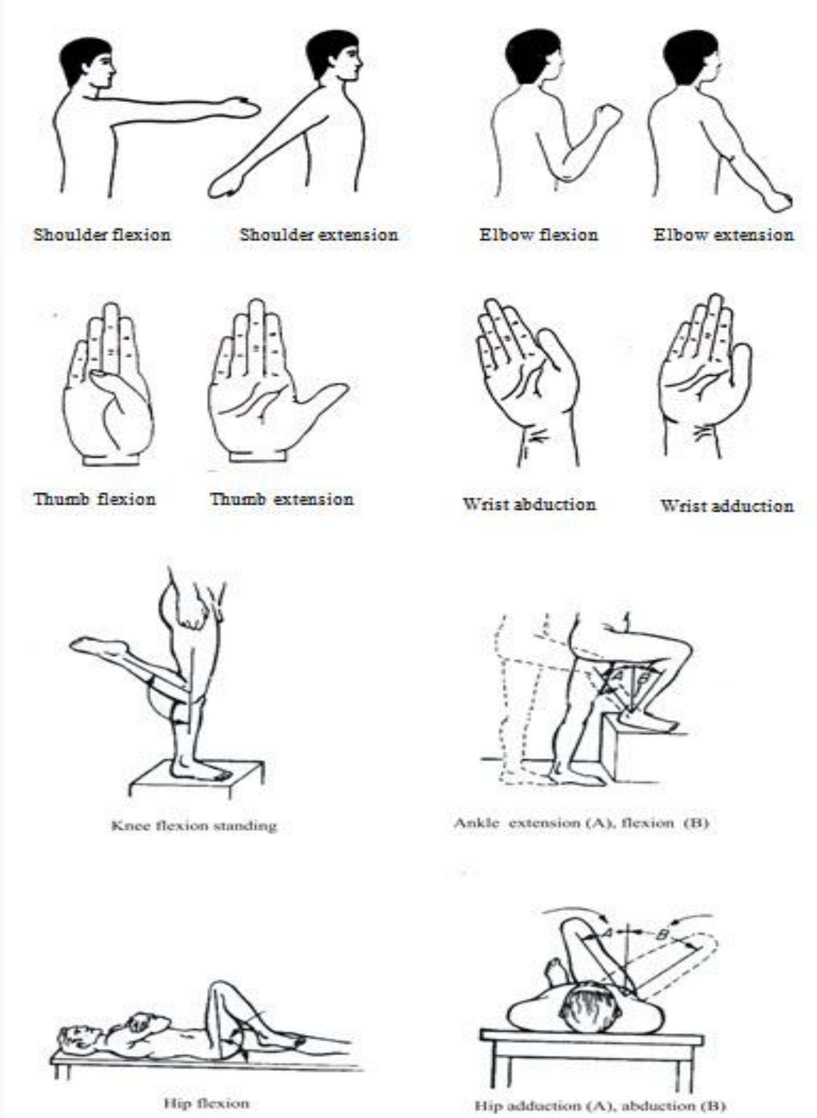
7.5 Types of movements of body members:

The movements which the arms, legs and other body members are capable of performing can be considered as basic are gliding and angular movements. Gliding is the simplest type of motion which exists between two adjacent surfaces. It is one surface moving over another without any rotary or angular motion. Angular motion decreases or increases the angle between two adjoining bones. The common types of angular motion and their description are described in Table.7.2

Table. 7.2. The common types of angular motion and their description:

S.No.	Terminology	Description
	Flexion	Bending parts at a joint so that the angle between them decreases and the parts come closer together i.e. bending the arm or leg.
	Extension	Straightening parts at a joint so that the angle between them increases and the parts move farther apart i.e. straightening or unbending the forearm, leg, or

		fingers.
	Dorsiflexion/ Plantar flexion	Movement at the ankle that brings the foot farther from the shin i.e. walking or standing on toes.
	Abduction	Moving a part away from the midline i.e. lifting the upper limb horizontally to form a right angle with the side of the body.
	Adduction	Moving a part toward the midline i.e. returning the upper limb from the horizontal position to the side of the body.
	Hyperextension	Extension of the parts at a joint beyond the anatomical position i.e. bending the head back beyond the upright position. This is generally used to describe an abnormal extension beyond the normal range of motion resulting in injury.
	Medial Rotation	Turning toward the mid line of the body. i.e. twisting the head from side to side.
	Lateral rotation	Turning away from the mid line of the body
	Circumduction	Moving a part so that its end follows a circular path i.e. moving a finger in a circular motion without the hand.
	Rotation	Movement of bone around its long axis, such as the rotation of the humerus in the upper arm.
	Pronation	Turning the hand so that the palm is downward or facing posteriorly i.e. in anatomical position.
	Supination	Turning the hand so that the palm is upward or facing anteriorly i.e. in anatomical position.
	Eversion	Turning the foot so the plantar surfaces faces laterally.
	Inversion	Turning the foot so the plantar surfaces faces medially.
	Retraction	Moving a part backward i.e. pulling the head backward.
	Protraction	Moving a part forward i.e. thrusting the head forward.
	Elevation	Raising a part i.e. shrugging the shoulders.
	Depression	Lowering a part i.e. drooping the shoulders.


Shoulder flexion
Shoulder extension
Elbow flexion
Elbow extension
Thumb flexion
Thumb extension
Wrist abduction
Wrist adduction
Knee flexion standing
Ankle extension (A), flexion (B)
Hip flexion
Hip adduction (A), abduction (B)

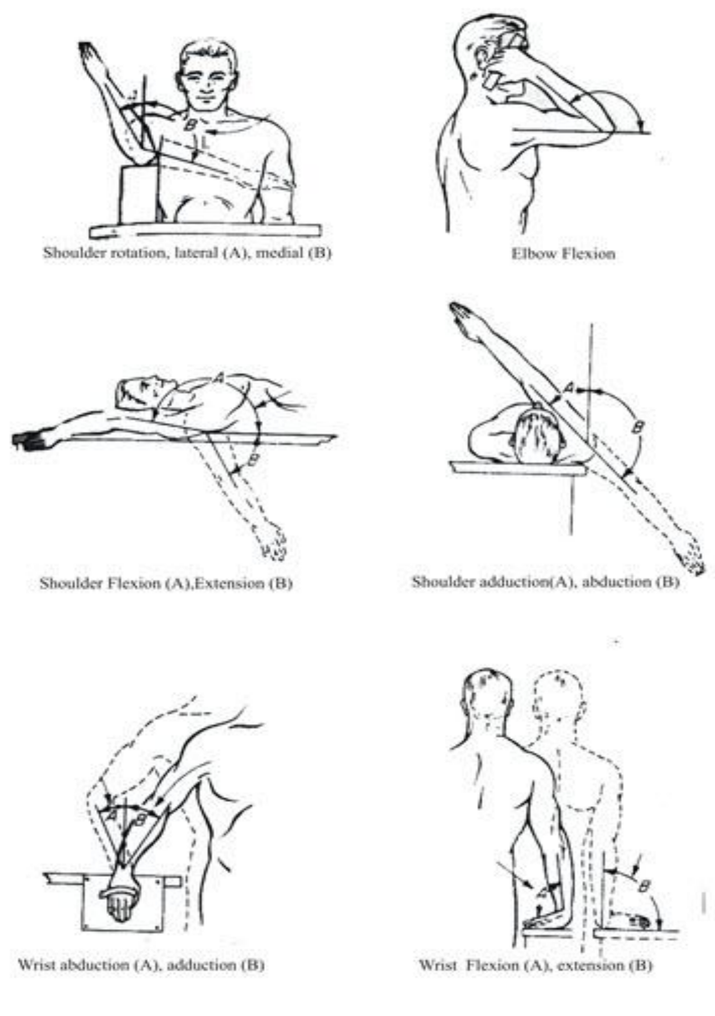


Fig. 7.2. Types of movements

There are more operational terms of the body parts with respect to the performance of specific activities of work. These movements can be classified as below:

Positioning Movements: Positioning movements are these in which the hand or foot moves from one specific position to another, as in searching the control knob. The time and accuracy of such movements can be influenced by such factors as the nature of the stimulus that triggeres the movement, the distance and the direction of the movement.

Continuous movements: Continuous movements are those which require muscular control adjustments of some type during the movement, as in operating the steering wheel of a car or guiding a pieces of wood through a band saw.

Manipulative movements: The manipulative movements involves the handling of parts, tools, control mechanism etc. typically with the fingers or hands.

Repetitive movements: Repetitive movements are those in which the same movement is repeated as in hammering, operating a screw driver and turning a hand wheel.

Sequential movements: Sequential movements are several relatively separated independent movements in sequences.

Static adjustment: It is the absence of a movement, consistency of maintaining a specific position of a body members for a period of time. Various types of movements may be combined in sequence so that they blend one in to another.

7.6. Precautions to be taken during work movement

i) Body joints must be in a neutral position

While maintaining a posture or making a movement, the joints should be kept as far as possible in a neutral position because the muscles and ligaments which span the joints are stretched to the least possible extent and subjected to less stress. Beside this, the muscles are able to deliver their greatest force when the joints are in the neutral position. Raised arms, bent wrists, bent neck and turned head, bent and twisted trunk are examples of poor postures where the joints are not in a neutral position e.g. raised arms, bending posture etc.

ii) Always keep the work close to the body

If the work is not close and far from the body, the arms become outstretched and the trunk bent over forwards. The weight of the arms, head, trunk and also the weight of any load being held, exerts a greater horizontal leverage on the joints under stress i.e. shoulder, back, elbow etc. when the arms are outstretched, it increases the stress on muscles and joints

iii) Avoid bending forward

Continuous bending for long periods must be avoided wherever possible. The weight of upper part of the body is generally higher than the lower part. The further the trunk is bent forwards, the harder it is for the muscles and ligaments of the back to maintain the balance of upper body. The stress is particularly large in the lower back.

iv) Avoid twisted trunk

The posture of the twisted trunk must be avoided. Twisted postures of the trunk can cause stress to the spine. The elastic discs between the vertebrae are stretched, and the joints and muscles on both sides of the spine are subjected to asymmetric stress.

v) Avoid sudden movements

The sudden movements and forces must be avoided, it can cause acute back pain in the lower back and can produce large/short duration stresses. These peak stresses are a consequence of the acceleration in the movement. Lifting must occur as far as possible in an even and gradual manner. Proper preparation of lifting large force should be done in even and gradual manner.

vi) Avoid prolonged postures and repetitive movements

Always avoid **prolonged postures and repetitive** for a long period of time which involve regular lifting or repetitive arm movements. These posture and movements are tiring, and can cause to injuries to the muscles and joints. The ill effects of prolonged postures and repetitive movements can be prevented by alternating tasks, i.e. standing, sitting and walking should also be alternated.

Lesson 8. STRENGTH AND ENDURANCE, SPEED AND ACCURACY, HUMAN CONTROL OF SYSTEM

8.1 Strength and endurance

Strength is the maximum force, that muscle can exert isometrically in a single voluntary effort, that is the muscular capacity to exert force under static condition. Human strength is a measure of an individual's physical capabilities, especially ones that permit a person to exert force or sustain external loading without inflicting personal injury (Mital and Das, 1987). Determination of human strength capabilities is necessary to design and develop engineering guidelines. Upper body strength is frequently required for performing manual tasks in domestic, agricultural and industrial environments. Hence it is very important to know the maximum strength capabilities of humans to design the different equipments and machines to match the capabilities of the worker and to working with safety without injury. Since most human activities consists of dynamic efforts rather than static efforts. Knowledge of worker strength is very important in designing tools, equipments and machines to improve the human work interface.

Muscle/ arm strength and endurance are two important aspects of neuromuscular performance.

8.1.1. Muscular/ Arm Strength –The ability of a muscle to exert maximum force against resistance; 1 RM (Repetition Maximum). Muscular strength is the ability to generate force with a muscle or group of muscles; whereas, muscular endurance is the ability to perform repeated contractions with a muscle or group of muscles. Strength is the maximal force muscle can exert isometrically in a single voluntary effort, that is, the muscular capacity to exert force under static conditions and is usually measured by the use of an external device such as hand dynamometer or a device for measuring the force exerted against some object.

8.1.2. Muscular Endurance – The ability of a muscle to exert sub-maximal force repeatedly over a period of time. The difference between muscular strength and muscular endurance can be better understood by reviewing how each is assessed. Muscular strength is assessed by determining the maximal amount of force that an individual can apply against resistance-one time (1 RM), such as with a bench press or possibly a push up. Muscular endurance is assessed by determining how many times that an individual can apply sub-maximal force upon a weight (or body weight), such as bench-pressing x pounds twenty five times, or the total number of sit-ups, or push-ups one can perform.

Endurance time is defined as the maximum amount of time a subject could continuously hold a given weight in a specified posture. Beyond this time the subject could no longer hold the weight due to fatigue or pain in the shoulder girdle

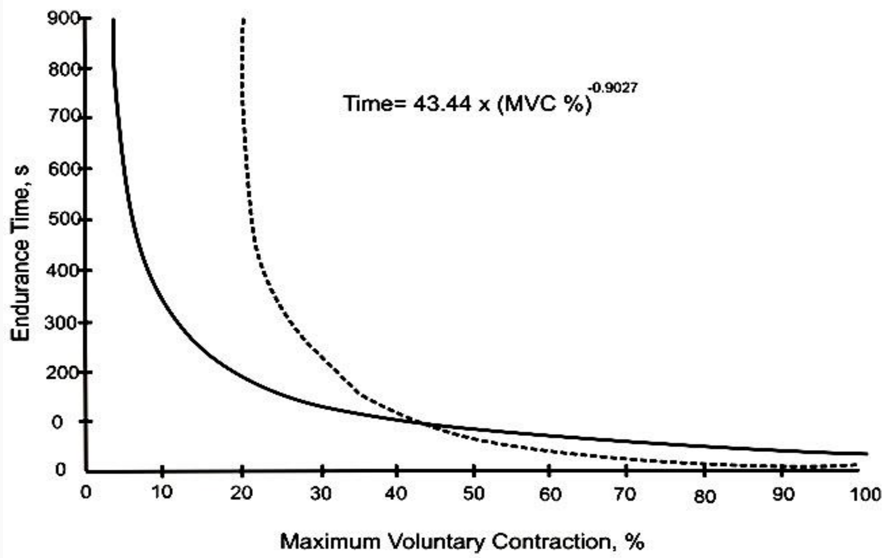


Fig 8.1. Endurance time (seconds) as a function of force requirements of tasks (maximum voluntary contraction)

8.2 Limit of Endurance

It is the ability to keep up some general body activity over a period of time. The endurance of a operator would be a function of the total energy cost of the activity and the energy expenditure the operator can reasonably maintain over time. If energy costs exceeds from the reasonable limits, rests should be provided to keep total energy requirements within bounds. Continuous stress on certain muscles in the body as a result of a prolonged posture or repetitive movement leads to localized muscle fatigue, a state of muscle discomfort and reduced muscle performance. As a result, the posture or movement cannot be maintained continuously. Garg et al. (1999) determined the endurance times for a continuous hold as a function of per cent maximum voluntary contraction (MVC) and shoulder flexion angle. Endurance time was defined as the maximum amount of time a subject could continuously hold a given weight in a specified posture. Beyond this time the subject could no longer hold the weight due to fatigue or pain in the shoulder girdle. The endurance decreased non linearly with the increase in % MVC. **Fig. 8.1** depicts the general pattern of endurance time as function of force requirements of the tasks. The greater the muscular effort (exerted force as a percentage of the maximum force), the shorter the time it can be maintained. Most people can maintain a maximum muscular effort for no more than a few seconds and a 50 per cent muscular effort for no more than approximately two minutes as this causes muscular exhaustion (Jan Dul, 1993).

8.3 Factors affecting muscular/ arm strength: The ability to exert extremely great forces depends on muscle mass and the utilization of energy stores in the muscle itself. Many factors can influence the human strength to carry out physical work. The factors can be broadly classified in two groups, (i) Personal and (ii) Environmental.

8.3.1 Personal factors: Personal factors may be age, body weight, gender/sex (male/female), consumption of drinking/ smoking/drug consumption, training, instruction, motivation, nutritional status and general health etc, which has been described in Table. 8.1

Table.8.1 Personal factors affecting muscular/ arm strength

S.No.	Factors	Description
1.	**Age**	Age has a significant effect on work capacity. VO_2 max declines gradually after 20 years of age. A 60 years old has an aerobic capacity of about 70 % of that of 25 years old. This declination is due to a reduction in cardiac output. Current thinking stresses that the fundamental aging phenomenon is due to a loss of muscle function.
2.	**Weight of body**	Body weight (particularly the percentage of body tissue which is composed of fat) influences all activities in which the worker has to move his/ her own body (eg. Walking, climbing on ladders or stairs)
3.	**Sex (Male/Female)**	Women's strength is about two-thirds that of man. Women have a lower VO_2 max than men and usually have a higher percentage of body fat. They also have less haemoglobin than men. The cardiac output per litre of oxygen uptake is higher in women than in men.
4.	**Consumption of Drinking/ Smoking/ drugs**	Alcohol may increase cardiac output in sub maximal work, thereby reducing cardiac efficiency. It also affect liver function and cause a predisposition to hypoglycaemia (low blood sugar). Tobacco smoke contains about 4 person by volume carbon monoxide (CO). CO has affinity for haemoglobin 200 times as powerful as oxygen. Smoking therefore reduces work capacity by reducing the oxygen carrying capacity of the blood. It also contains very large number of toxic and carcinogenic chemicals and causes chronic damage to the respiratory system, which are likely to have a generally depressing effect on the physical capacity of smokers.
5.	**Instructions and motivation**	Work capacity can be enhanced by physical training in more efficient work methods. Over a period of several months, the muscle fibers increase in size as a result of an increase in number of myofibrils, and an increase in strength is observed. A worker's level of motivation may be affected by intrinsic factors such as personality, personal and career goals, need for achievement at work and so on, as well as extrinsic factors such as work organization, method of remuneration and the availability of alternative forms of employment. Exercise can increase strength and endurance within limits, these increase frequently being in the range of 30 to 50per cent above beginning level.
6.	**Nutritional diet and Health**	A balanced diet is important to ensure adequate amounts of necessary food stuffs and to minimize the accumulation of excess body fat. A lack of carbohydrate in the diet can reduce work strength or other complications which affect work capacity.

8.3.2.Environmental Factors: Many environmental factors can degrade strength and work capcity of the worker, viz. atmospheric pollution, air quality, ventilation, altitude, noise, vibration, extreme heat or cold etc as described in Table. 8.2.

Table.8.2 Environmental factors affecting muscular/ arm strength

S. No.	Factors	Description
1.	**Atmospheric condition and pollution**	Atmospheric condition and pollution may increase the resistance to air flow of the respiratory airways and in long term cause damage to the lungs, permanently reducing the worker's capabilities.
2.	**Noise condition**	Noise is a stressor which can elevate the heart rate and reduce cardiac efficiency.
3.	**Altitude**	The capacity for sustained work is reduced at high altitude because the partial pressure of oxygen is lower (air becomes 'thinner' with the increasing altitude). The strength for maximum muscular work remains unchanged up to an altitude of 1500 m above mean sea level. Above 1500 m maximal work capacity decreases by about 10 percent per 1000 m (Kroemer, 1991).

8.4. Speed and accuracy

One of the major determinants of inspection accuracy is speed of working. Speed generally is the primary requirement in executing movements that are otherwise not difficult or demanding, such as in applying the brake pedal of an automobile or reaching for parts to be assembled.

In turn accuracy is the primary requirement in executing such movements as those in tracking (in which continuous control is required), in certain positioning actions that require precision and control, and in certain manipulative activities. However, in some circumstances both speed and accuracy may be required. Speed and accuracy are expected to be inversely related. We have experienced speed–accuracy trade-offs many times as you have completed various tasks. For example, we know from experience that the faster we move our computer mouse, the more likely we are to miss the icon you are moving to click. Just as speed is often measured by its reciprocal. time, similarly accuracy is measured by its complement, errors.

An error-free performance, in a discrete task, is an accurate performance. Drury (1991) follows many others in concentrating on error probability, or error rate, defined as:

$$p\,(\text{error}) = \frac{\text{number of errors}}{\text{number of opportunities}} \qquad \text{........ (i)}$$

For repetitive tasks, error rate is typically defined per cycle, so that we have sewing errors per 100 pair of jeans, near misses per flight.

8.4.1 Response time

The time required to make certain responses can be influenced by a number of variables, such as the nature of the stimulus, the number of choices, the degree of expectancy, and the device used. In some instances the total time required can be of substantial consequence. For example, the response time of the pilot of a supersonic aircraft on a collision course can be as long as 1.7 s, this being the simple addition of 0.3 s for visual acquisition of the other aircraft, 0.6 s for recognition of the impending danger, 0.5 s for selection of a course of action, and 0.3 s for initiation of the desired control response. Add the response time of the aircraft itself and it would be futile to take any action if the planes were closer than about 4 miles. The reaction time is used to describe the means by which the signals or data is conveyed to the central mechanism. It is the time taken to respond the data or signals.

8.5. Human control of system

There are many functions whose identifications needs intelligences, can be performed by human in a better way unless it is highly complex. Some of the functions performed by human are:

i) Human being can sensing minimum stimulate from a wide range of sources and complete the signals to bring a complete event or task.

ii) Human can amplify the signals or take some action in reference to what he has perceived.

iii) Human can perceive a signal in three dimensions and can interpolate and extrapolate. Human can do prediction also on the basis of signal data or sign boards, signal of speed limit, speed breaker, railway crossing ahead etc. would automatically cause the operator/ driver to slow down the vehicle for fairly accurate judgement.

8.5.1 Muscular control movement

Generally physical work is performed by the activation or control of musculoskeletal system. Muscle constitutes about 45% of the total body weight and plays the most important role in working efficiency. The most important characteristics of muscle tissue is its ability to contract with a certain force. The force of muscular contraction depends upon the number of activity contracting muscle fibre and the speed depends upon the amount of force exerted with in a fixed time which is regulated by the number of fibres activity contracting that time.

8.5.2 Nervous control Movement

The brain of human body is connected with each muscle and therefore the nervous system is to control the body organs activity. During stimulation nerves cells send out impulses along the nerves fibres to the concerned organs.

Each muscle is connected to the brain by two types of nerves i.e sensory and motor nerves.

Sensory nerves: Sensory nerves begin in the muscle spindle, which are stimulated by the change in tension and length of muscle and send impulses along with the sensory nerves in the spinal chord. These sensory impulses are finally perceived in the brain as sensations of hearing, vision, taste, position, force and tension. For the delicate of muscular movement, they provide information about the state of muscular system.

On the strength of the visual information, brain controls the further sequence of movements. When the object is grasped, new information reaches the brain alters the grip pressure, this process continues till the work is accomplished.

Motor: This motor nerves actually controls the actions of muscle. The microvolt action difference is transmitted to the muscle fibre through motor in the form of pulse and which intern controls the force, speed and movement of muscle. The nerve impuls originate in spinal chord whereas a sequence of reflex in spinal chord, whereas a sequence of reflex activities, action potentials are submitted in the motor nerves.

Lesson 9. HUMAN MOTOR ACTIVITIES, CONTROLS, TOOLS AND RELATED DEVICES

9.1 Human motor activities

Human activities that fall within optimum level of intensity i.e. mental psychomotor and physical activities. The intensity of work activity increased with the increase in likelihood of boredom, i.e. mental to physical. The nature of human physical responses and activities have implications for many aspects of human factor, viz. the design of control devices, hand tools and other devices, handling of materials, physical layout and arrangement of workspace methods and procedures.

The immediate output of human activity is most job situations include the execution of physical responses or communications, which accomplish some desire objectives. The ability of operation to perform various types of motor activities depends upon the physical structure of the body, the skeletal muscle, nervous system and the metabolic processes.

9.1.1. Physical Skeletal Structure:

The physical structure of the body consists of Skelton formed by 206 bones. These bone structures serves the purpose of housing and protecting the essential organs (skull and ribcage) of the body. The skull protects the brain and ribcage protects the lungs, heart, and other internal organs. The upper and lower extremist and the articulated bones of the spine are concerned primarily with the execution of physical activities.

9.1.2. Skeletal Muscle structure:

The skeletal muscle consists of bundles of muscle fibres which seems to convert chemical energy in to mechanical work. The bones of the body are held together at their joints by ligaments. The two end of each muscle blend in to tendons, which intern are connected to different skeletal bones in such a manner that due to activation of muscles, some form of mechanical leverages applied.

9.1.3. Neural Control activity of muscles:

Neural control of muscle activities can be controlled by sensory nerves and motor nerves, which has already been discussed in section 8.5.2.

9.1.4. Muscle metabolism:

It is the collective chemical process of conversion of food stuffs into two forms, i.e. mechanical work and heat work. Some of the mechanical work is used externally as in physical tasks. Usually heat is generated in surplus amounts, which must be dissipated by the body. The contraction of muscle require energy which is formed by glycogens. The conversion of glycogens in to energy consists of a chemical reaction, that ends in the production of lactic acid. At the initiation of physical activity the muscle can utilize the glycogen in to energy.

When an adequate amount of oxygen is supplied, the accumulation of lactic acid is very little. If the activity level requires more oxygen then is provided by the normal blood flow rate through cardiovascular system. The increased demands adjusted by the system. This increased demand is adjusted by increasing the heart rate to pump more blood through cardiovascular system. The blood is pumped from the heart through the lungs, where it picks up a supply of oxygen, which is then carted by the blood to the muscle where oxygen is needed. At moderate rate of work activity, the heart rate and breathing rate are normally increased to the level that provides enough oxygen to perform the physical activities over a continuing period of time. At thigh rate of work activity, when the amount of oxygen delivered to the muscle fails to meet the requirements, lactic acid tends to accumulate in the blood. At continued duration of physical activity the muscle will ultimately cease to respond.

9.2 Control:

A control is a device that enables an operator to change the state of a mechanism. It convert the output of an operator into the input of a machine controls are pieces of hardware and are after regarded as parts of a machine but for design purpose they can be considered as links between the machine & the operator. A control transmits the information from the man to the machine and the starting point of design must be the output character ties of the operator.

Output devices of an operator:–

i) Four limbs (two hands & two feet)

ii) Voice (man to man vocal output is useful but for man & machine it is of no use.

Basic output of human limb is force: so the controls can be in the form of Pressure control and Displacement control.

9.2.1 Pressure control: is one that effectively does not move at all, but the force or torque exerted on it influences the machine.

9.2.2 Displacement control: is the one for which the change of state of the machine is a function of the distance or angel through which the control has been moved. The direct feedback from displacement controls is much more complex, since it depends upon the control restoring forces. They may not exist, in which case the control stays wherever it is put and feedback is a matter of sensing displacement.

The key feature of control as a function of applied force to be used effectively without vision. For this it is often useful to provide mechanical gates through which controls move and which provides pressure & displacement cues, which is turn enables the operator to know what he has done without looking at the control. This has been achieved in gear levers for motor cars and operation of such well designed control mechanisms is a source of pleasure for operator. This is regardless of which limbs, tomb and muscles are involved in control activation.

Seat Index Point (SIP):

The seat index point is the interaction on the central vertical plane passing through the seat centre line of the theoretical pivot axis between a human torso and thighs.

Seat Reference Point (SRP):

The seat reference point is the point in the central longitudinal plane of the seat where the tangential plane of the lower backrest and a horizontal plane intersect. The SIP is located 90 mm above and 140 mm in front of SRP (Fig.9.1).

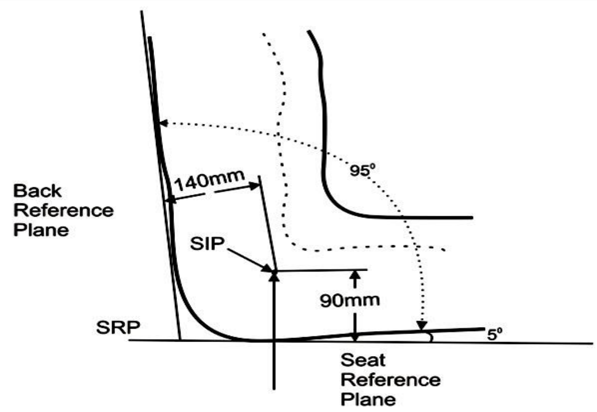


Fig. 9.1. Position of Seat Index point and Seat reference point to seat and reference plane

9.2.3 Placement of the controls in optimum areas

The concept of optimum dimensions and limiting dimension is used in the placement of controls in space and it applies to both manual and pedal areas. The optimum dimensions define the most desirable space for the location of controls both in their neutral position and when displayed in any direction. This is an ideal' area reserved primary for the most important controls together with those which are used frequently. The limiting dimensions define the acceptable but not the most desirable space or the location of controls. If controls are placed outside the space, they are neither too close nor too far from the operator. The dimensions usually chosen to define the boundaries of these spaces are estimated to cater for 90% of the operator population that is from the 5^{th} to the 95^{th} percentiles.

Two types or controls namely operated by hand and foot are considered. Foot control are best for provision of powerful or continuous forces and hand controls are used for speed and precision. A maximum of 4 foot controls can be operated by an operator in the absence of highest degree of practise and skill. Assuming that the operator is seated and can maintain equilibrium without relying on his feet. Standing operator cannot use foot controls without extensive postural adaptation. Because it is uneconomic in speed & energy expenditure wide individual differences in the ability to coordinate hand and foot control movements.

9.2.4 Grouping of control location and actuating forces

While arranging the controls within the work place area, three major factors i.e. priority, grouping and association should be considered. Priority depends on the frequency and extent of use. The highest priority controls should be place within the optimum spaces.

Emergency controls must be placed in readily accessible positions. Secondary controls should be placed within the limiting areas but not necessarily in the optimum area. Setups and calibration controls, which are used infrequently, may be located outside the operator's normal work space.

Grouping may be done generally by functional and sequential grouping. In functional grouping all controls, which are identical in function (eg. Light switches) or used together in a specific task (e.g. position and draft control) are grouped together. In sequential grouping controls are grouped and arranged in normal order of use.

Control location and actuating forces

Hand controls

Hand controls should be used in preference to foot control where (i) accuracy of control positioning is important. The hand and arms are much more accurate than feet and speed of control positioning is required. (ii) Continuous or prolonged application of moderate or large forces (20 ibf, 89N or more).

The seated position is preferable to the standing position especially if the controls are to be operated for any length of line. Standing is more fatiguing and usually results in less efficient, weaker or less accurate control of movements. One hand controls are preferable to those operated with hands, for precision and speed, except that large diameter control wheels with reciprocating motion (steering wheels) are operated with two hands. Where larger forces are required, and operation controls are to be used. The preferred hand – be used where speed, accuracy or strength of the control movement are important. The recommended dimension for the optimum manual control of male operators is about 24'' (600 mm) wide, 12'' (300 mm) either ride of the midline. The Fig. 9.2. shows the optimum with respect to a horizontal seat cushion and is valid for a – seated with back vertical.

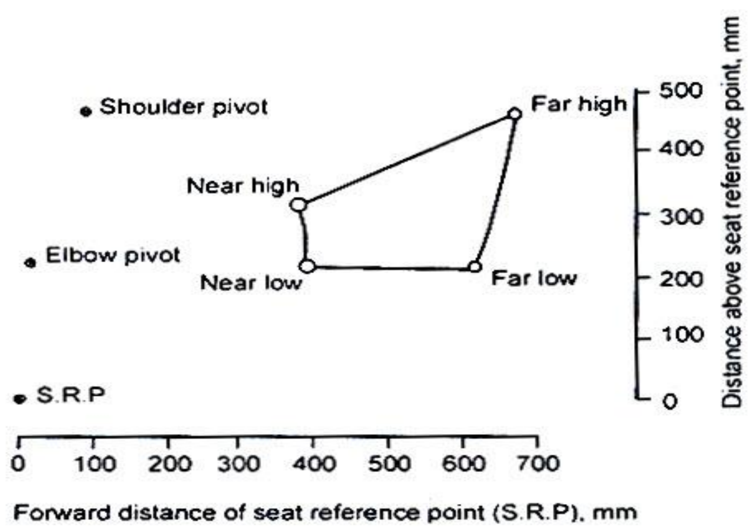


Fig.9.2. Optimum area of hand controls for adult operators in seated position

Then all the controls cannot be placed within the optimum location immediately adjacent to the optimum control areas more desirable than those dimensions than those farther away. Normally the dimensions of the controls placement are given w.r.t seat reference point. For those dimensions to be applicable in all the reference point should be adjustable at least 125 mm horizontally and 125 mm vertically.

The variety of hand controls is commensurate with the versatility of the hands. Steering wheel is the hand equivalent of the rudder-bar and has the corresponding advantage of achieving precision by balancing forces between the two hands. It makes possible a wide variety of position & type of grip (hand grip) and operation by either hand or by both hands and can also provide a large torque.

Ideally the optimum vertical location of controls for the standing operator would tie between the shoulder level and the elbow level with the arms at the side of the body. If this area is to be optimised both tall and short operators (lower limit at height of small operator), the residual area would be too small to be practical value. The best alternate is to use the dimensions of the average (50th percentile) operator.

Table.9.1. Maximum operating forces required for operating tractor controls

S. No.	Devices to be operated	Type of control	Maximum actuating force to operate control (N)
1	Service brake	Pedal Hand lever	600 400
2	Parking brake	Pedal/ Hand lever	600 400
3	Clutch	Pedal	350
4	PTO coupling	Pedal/ Hand lever	300 200
5	Manual Steering system	Steering Wheel	250
6	Hydraulic power lift system	Hand lever	70

Foot controls

Foot controls are to be used in preference to hand controls where, i) there is a continuous control task in which precision or control positioning is not of primary importance, ii) the application of moderate to large forces greater than **20-** Ibf (89-199n) is necessary intermittently or continuously, iii) the hands are in danger of being overburdened with control tasks. Pedals may be divided into two groups: those designed for use when the force is above 10-20 Ibf (44-89N) and is obtained by movement of the leg (brake pedals) and those where the force is obtained primarily from the ankle (e.g. an accelerator pedal) which should be used where small forces of about 10 Ibf (44N) or less & continuous operation is required

(**Table.9.1**). The long axes of the foot and lower leg should the foot in position. The optimum pedal area which is most desirable for the location of the foot controls both in their natural position and when displaced in my direction in shown in **Fig 9.3**. In locating foot controls for the seated position within these optimum areas, there are three considerations: the locations fore & aft location, the vertical location and the lateral locations. Fore & aft seat reference point to pedal distance is an important determinant of the amount of pressure exorable on the foot control. The shorter the distance, than the force exertable, pedals can be placed below the S.R.P. by vertical distances varying with the type of task. As pedals are moved laterally from midline of the leg, the force exertable.

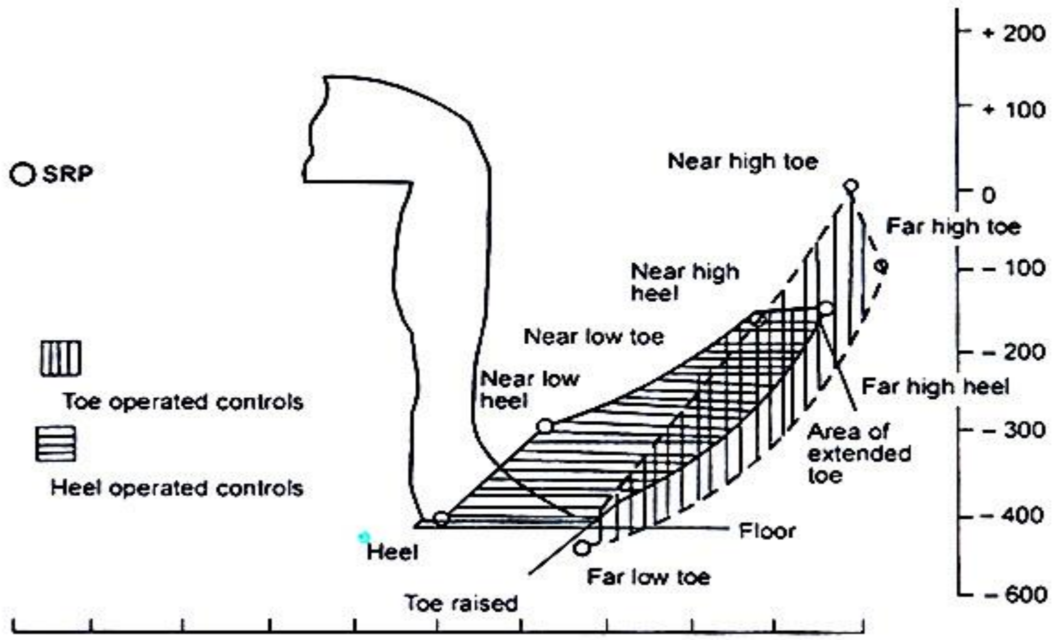


Fig. 9.3 Optimum area of foot controls for adult operators in seated position

Foot controls should be designed to be operated from the created position. For the seated position, a backrest should always be provided. There is little difference between the legs with regard to strength, speed or accuracy but most people prefer the right leg especially for critical tasks. Common foot controls are pedal, rotating pedal, beadle, rudder bar and rotating platform. Pedal design is largely an anthropometric problem of placement in relation to the floor and seat. It is essential to have adjustable seat. Pedal should be provided with 1.non-slip surface 2. Restoring force should be large enough to support to the weight of the foot. Rotating peddle & treadle are really relics of the times when it was necessary to provide rotation by reciprocal foot activity e.g sewing machines and potter’s wheels. Rotating platform is particularly useful for adjusting the orientation of machine or material in relation to the operator’s hands.

Brake pedal : Operating a brake or clutch pedal of a tractor requires the driver to exert a force so as to move the pedal at prescribed distance along its axis of travel. The first requirement for accident prevention is that brakes operate quickly and easily, therefore it is greatest convenience for the operator results from locating the brake pedal directly in front of the normal foot position.

Clutch pedal : the clutch pedal is used very frequently even more frequently than the brake pedals. Therefore it is necessary for the operation of clutch pedal is usually smaller than that required for brake pedals. Therefore it should be located in a position symmetrical with the brake pedal, with the centre axis of driver serving as the symmetrical axis for both.

Accelerator pedal: control of engine speed by means of a foot accelerator is easier than by hand throttle lever, because the hand is required for steering, gear shifting lever, operating hydraulic controls and engaging parking brakes. The ankle joint is particular suited to sense a position and maintain close regulation; 200 movement of the ankle affords a sufficient degree of accuracy. In addition to the magnitude of pedal motion, the force necessary to operate the pedal is of great significance for accurate regulation of engine speed. If pedal pressure is too high, the energy required to continuously operate the pedal will be excessive.

9.6 Tools and related devices

Probable there are couple of interrelated consideration dominant in the design or selection of many hand tools, equipments that are used in various domestic, agricultural and industrial operations, i.e khurpa, sickle, kasola etc. Certainly these tools and devices need to be capable of performing their function, such as digging soil, cutting crops etc. The mechanization revolution brought about the use of machines for doing such operations. The invent of machine typically required that people exercise control, controls by some control by hand or foot control mechanism.

Lesson 10. ANTHROPOMETRY

M-III.10. ANTHROPOMETRY

10.1 Introduction

Anthropometry is the branch of the human science that deals with the data described by the size of human body measurements including body dimensions and the other physical characteristics and mechanical aspects of or the human body motions. Anthropometry is the technology of measuring various human traits as size, mobility and strength, whereas engineering anthropometry is the effort of the operator since human machine interface decides the ultimate performance of the equipment/work system. There is a large variation among body dimensions it is not economical or sometimes practically feasible to design the equipment/work places so as to suit 100% of the users. Therefore, generally the design is made in such a way so as to satisfy 90% of the users. This is achieved through use of 5^{th} and 95^{th} percentile limits. It means that those people who fall outside these limits will not be matched with respect to the criteria concerned. They will be able to use the equipment but may be with less efficiency and comfort. Anthropometric measurements are a critical element in equipment and workspace design. With the familiar with anthropometric data and its applications the work system, equipments, tools and jobs for proper fit to the human, to achieve safe and efficient operation. For example a tractor seat is designed, so the backrest, hand rest, seat cushion, seat width should be based on anthropometric data of farm workers.

10.1.1 Basic Ergonomics Design Principles:

a) Design for the average: The design of average is not fit for anyone. Because no one is average in all dimensions. These designs are utilized for design public facilities like public transport buses seats, roadside benches, these facilities are used by a large variety of peoples.

b) Design for the extremes: The extremes value may be large or very small for examples a tractor seat is designed for accommodate a range of persons, if the person is for heavy or the largest person or the smallest, so it may be not suitable for extremes.

c) Design for a range: it is the most common design philosophy and commonly used by the ergonomic to design arrange of population. A typical range of 5^{th} and 95^{th} percentile of population is used such a design would be expected to accommodate 90% of population.

10.2. Measurement of Anthropometric data:

There are very few studies available on anthropometric data on agricultural workers, again which are mainly case studies and involving only male workers. Therefore, a comprehensive data base involving 79 body dimensions and 16 strength parameters of at least 1000 agricultural workers (male : female :: 70% : 30%) as formulated by the ICAR is a major step towards future machinery design and development and also for modification in design of the existing machinery.

10.2.1. Equipments used for Measurement of Anthropometric Dimensions

a) Anthropometric equipment type A : It consists of a fixed pipe structure rigidly attached to a pentagonal base. Several lateral pipes are attached to the main pipe. All the steel pipes bear a linear metric scale so that measurement can be easily taken. The pipes can also rotate about their axis and locked in any position with the help of wing nuts.

b) Anthropometric equipment type B : It consists of several square section tubes which bear linear scale in centimeters. The tubular sections can be prolonged by sliding and inserting one end into the other. A veneer provision helps taking down various kinds of and difficult measurements. A span of 210 mm can be measured with this equipment. However, minimum distance measurable being only 0.6 cm (Fig.10.1).

c) Anthropometric seat/ chair : It consist of a number of angled iron which are arranged together to form a seat. The seat surface and the back one are made of plywood. The seat height is of 600 cm while the back being 100.0 cm & the width and length being 50.0 and 70.0 cm respectively. In accordance with the data requirement, the seat surface slides along the slots in the four legs of the seat for a distance of 24.0 cm vertically while horizontally it is 14 cm.

The seat surface board is fixed and fastened by tightening the four set of nuts and bolts. According to the comfort at the subject, the seat height is adjusted by loosening and then tightening the four set of bolts and nuts. This prepares the subject to undergo anthropometric test of data collection (Fig.10.1).

The equipments consisted of the following:

i) Anthropometer in canvass bag for measurement of length 0-960 mm on one side and 0-2100 mm on opposite side.

ii) Base plate for anthropometer.

iii) Re-curved measuring branches for anthropometer.

iv) Martin type sliding caliper used for measuring length up to 200 mm and depth up to 50 mm.

v) Spreading caliper with rounded ends having a measuring range of 0-600 mm.

vi) Skin fold caliper for measuring skin fold dimensions.

vii) Plastic tape of length of 2000 mm.

Grip cone

A truncated cone having a height of 27.8 cm was fabricated for measuring grip diameter (inside as well as outside). Its diameter range varied between 35-95 mm. Another cone of height 18.8 cm was fabricated for measuring middle figure–palm grip diameter. This cone has a measuring range of 10-40 mm.

Weighing balance

A spring type weighing balance having a least count of 0.5 kg and a range of 0-130 kg was used for measuring body weight of the subjects.

10.3. Procedure for measuring Anthropometric dimensions:

1) Isolate the equipments and prepare the subject.

2) Let the subject stand on the pentagonal platform of anthropometric equipment type A.

3) Measure the height, while standing, and while sitting in accordance with the instruments depicted in Fig.10.4 (a)

4) Note the dimensions where the equipment type A and then introduce equipment type B. (Fig.10.2) Vice-versa is also possible

5) Record each reading according to specifications

6) Put the subject into the anthropometric seat and take the dimensions as per the diagram Fig.10.4 (b).

7) Repeat similarly to different number of subjects

Fig. 10.1 Equipments used for anthropometric measurements.

Fig. 10.2 Eye height

Fig.10.3 Olecranon

Fig. 10.4 Biacromial breadth

Fig. 10.5 Vertical grip reach

Fig. 10.6 Torque strength of both hands

Fig. 10.7 Hand grip torque

Fig. 10.8 Pull and Push strength of right hand in sitting

Fig. 10.9 Push and Pull strength of both hands in standing

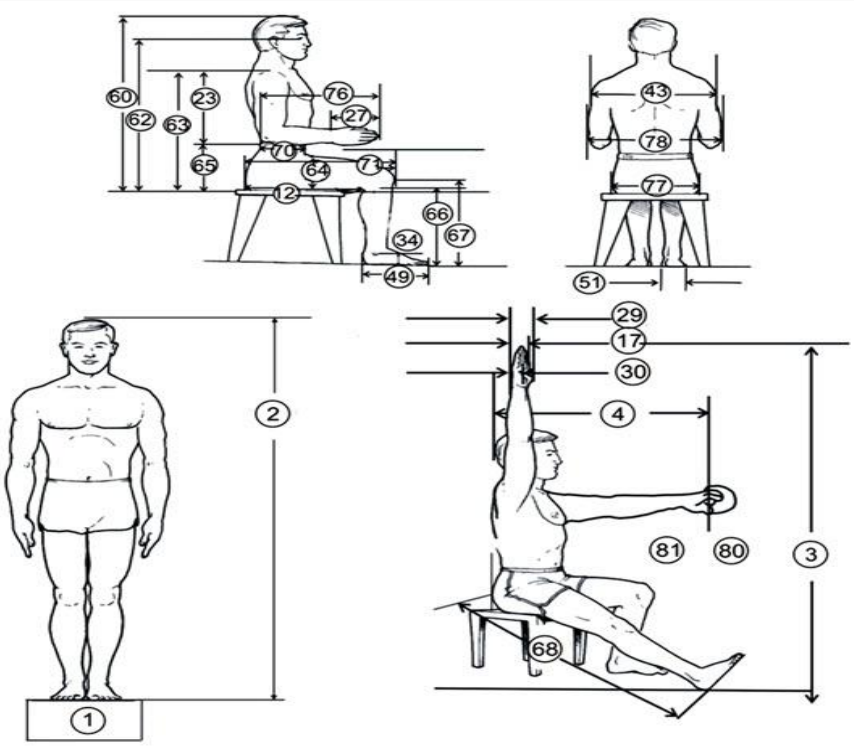


Fig.10.10 Measurement of Major Anthropometry Dimensions

(*Legend as mentioned in Table.10.1*)

10.4. Analysis of Anthropometric Data:

Human being must not only fit spatially in a man task system, but must also be able to move in the work space. With the aid of anthropometric data we can provide an optimum work space layout, including good posture, contributing to considerable decrease in work load and an improvement in the performance. Normally, during collection of human engineering data skip the first and last five percentile. Thus while designing a seat; it should be designed to accommodate a reasonable range of individuals, usually from 5^{th} to 95^{th} percentiles. Seat should be designed to take maximum weight expected. In order to realize a good performance, it is necessary that the movements of the body members are in synchrony, simple and logical motions are made, which can be performed almost automatically by the central nervous system. Lower percentile values of seat height and seat depth should be taken.

For Indian agricultural workers including male and female workers, the stature would vary from 1350 mm to 1830 mm, thus the range would be 1830-1350=480 mm. according to the formula given by Raghavrao (1983), the standard deviation can be estimated from range as follows:

$$S = \sqrt{\frac{(Range)2}{36}}$$

$$S = \sqrt{\frac{(480)2}{36}} = 80 \text{ mm}$$

It is defined as the ratio of weight of a person to his /her height squared (Keys, 1972)

$$BMI = \frac{Weight}{(Height)^2}$$

Measures of central tendency (mean) and dispersion (standard deviation) are good descriptive statistics of the distribution of the mass of data. Beside these two, there are two other characteristics of the distribution. These are Asymmetry also known as skewness (β) and Kurtosis or Peakedness (β_2).

The skewness (β_1):

$$\beta_1 = \frac{m_3}{(\sqrt{m2})^3} = \frac{\text{Third moment about the mean}}{(S.D.)^3}$$

Kurtosis (β_2): $$(\beta_2) = \frac{m_4}{m_2^2} - 3 = \frac{m_4}{(S.D)^2} - 3$$

For normal distribution, the value of β_1 as well as β_2 would be 0 to give the idea of distribution of mass data for different dimensions; the values of β_1 and β_2 have been calculated and given in here.

Table. 10.1 Anthropometric dimensions of agricultural workers

Sr. No.	Dimension	Definition	Usefulness
1.	Weight	Body weight as measured on a calibrated weighing scale.	General body description.
2.	Stature	The vertical distance from the standing surface to the vertex of the head when the subject stands erect and looks straight forward.	General body description, work place designs.
3.	Vertical reach	The vertical distance from the standing surface to the height of middle finger when arm hand and fingers are extended vertically.	Workplace layout, design of controls.
4.	Vertical grip reach	The vertical distance from the standing surface to the height of the pointer held horizontal to the subject's fist when the arm is maximally extended upward. The subject stands erect andlooks straight forward.	Workplace layout design of controls.
5.	Eye height	The vertical distance from the standing surface to the external canthus of the eye when the subject stands erect and looks straight forward.	Design of controls and displays.
6.	Acromial height	The vertical distances from the standing surface to the acromion. The subject stands erect and looks straight forward	General body description, work place layout, body linkages for deciding feeding chute height, for lifting studies for use in force application studies.
7.	Elbow height	The vertical distance from the standing surface to the top of the radiale when the subject stands erect and looks straight.	General body description work-place layout, body linkages.
8.	Olecranon height	The vertical distance from the standing surface to the height of the undersurface of the elbow measured with the arm flexed 90^0 and the upeer arm vertical. The subject stands erect andlooks straight forward.	Workplace layout body linkages, platform height for work to be done in standing posture like in workshop, kitchen etc.
9.	Illiocrystale height	The vertical distance from the standing surface to the top of the ilium in the mid axillary plane. The subject stands erect and looks straight forward. This is also known	Body linkages, safety harness design, safety belt design material

		as waist height.	handling height recommendation.
10.	Illiospinale height	The vertical distance from the standing surface to the height of the illiospinale. The subject stands erect and looks straight forward.	Body linkages safety harness design, safety belt design.
11.	Trochanteric height	The vertical distance from the standing surface to the height of the trochanterion. The subject stands erect and looks straight forward.	Body linkages, biomechanics study setting limit for leg lifting in sagital plane.
12.	Metacarpal III height	The vertical distances from the standing surface to the height of the knuckle where the middle finger joins the palm. Subject stands erect andlooks straight forward.	Control panel design, handle height of manual as well as animal drawn equipment handle height of manually operated rotary equipment.
13.	Knee height	The vertical distance from standing surface to the midpoint of knee cap. The subject stands erect andlooks straight forward.	Body linkages, work place design.
14.	Span	The distance between the tips of right and left middle fingers when the subject's arms are maximally extended laterally.	Work place design, design of controls.
15.	Span akimbo	The distance between the elbow point measured with the arms flexed and held horizontally palms down, fingers straight and together and palm and thumbs touching the chest at the nipple level.	Work place design, design of controls for material handling packages.
16.	Chest circumference	The circumferences of the torso measured at the nipple level. The subject stands erect and looks straight forward.	General body description health index, comparison of different populations, personal protective clothing design.
17.	Waist circumference	The circumference of the torso at the waist level. The subject stands erect and looks straight forward.	Personal protective clothing design, seat design harness design for backpack.
18.	Thigh circumference	The circumference of the upper leg measured as high in the crotch as possible.	General body description personal protective clothing design.
19.	Calf circumference	The maximum circumference of the gastrocnemius muscle in the lower leg. The subject stands erect and looks straight forward.	General body description personal clothing design, gumboot/safety shoe design.

20.	Wrist circumference	The circumference of the wrist at the level of the tip of the styloid process of the radius.	Biomechanics, gloves design wrist band design.
21.	Arm reach from wall	The distance from the wall to the tip of the middle finger measured with subject shoulder against the wall, his hand and arm extended forward	Design of controls and display panel, work place layout.
22.	Waist back length	The vertical distance along the spine from the waist level to the cervical (the tip of the seventh cervical vertebra). The subject stands erect andlooks straight forward.	Knapsack, rucksack and haversack equipment design.
23.	Scapula to waist back length	The surface distance from superior angle of scapula to the back at the waist level. The tape starts from the middle of the superior angle of the scapula, passes through the armpit and ends at the back at the waist level on the same vertical axis.	Knapsack sprayer design harness strap design (length of belt in knapsack sprayer), carrying basket in tea gardens.
24.	Wall to acromion distance	The horizontal perpendicular distance from the wall to acromion measured when the subject stands erect against a wall.	Body linkages, reach envelops knapsack design, biomechanics study.
25.	Wall to lumbosacral joint distance	The transverse distance from the wall to the posterior superior iliac spine. The subject stands erect against the wall and looks straight forward.	Biomechanics study seat design, workplace design.
26.	Abdominal extension to wall	The vertical distance from the most laterally protruding point of the abdomen to a wall against which the subject stands erect with minimal wall-buttock contact and looking straight forward.	Access design of control panel, biomechanics study, personal protective clothing design.
27.	Hand length	The distance from the base of the hand to the top of the middle finger measured along the long axis of the hand.	Handle design, control panel design, hand tool design.
28.	Hand breadth at metacarpal-III	The thickness of the metacarpal phalangeal joint of the middle finger.	Handle design, control panel design, hand tool design, safety guard design, maintenance space design, safety gloves design.
29.	Hand breadth across thumb	The breadth of the hand as measured at the level of distal end of the 1st metacarpal of the thumb.	Handle design, control panel design, hand tool design, safety gloves design hand grip design, knapsack sprayer trigger design.
30.	Hand thickness at metacarpal-III	The thickness of the metacarpal phalangeal joint of the middle finger.	Handle design control panel design,

			hand tool design, safety guard design, maintenance space design, and safety gloves design.
31.	First phalanx digit-III length	The length of first segment of the middle finger measured across the surfaces of the third metacarpal and second phalanx while the hand is held in a fist.	Handle design, control panel design, hand tool design, maintenance space design, space requirement for control knobs.
32.	Palm length	The distance from the base of the hand to the furrow where the middle finger folds upon the palm.	Handle design, hand tool design, design of push controls biomechanics study.
33.	Medial malleolus height	The height of the most medially projecting point of the medial ankle bone from the ground surface.	Safety shoe design, foot control design, foot rest design, biomechanics study.
34.	Lateral Malleolus height	The height of the most lateral projecting point of the lateral ankle bone from the ground surface.	Safety shoe design, foot control design, foot rest design.
35.	Bimalleolar breadth	The distance across the protrusion of the medial and lateral malleolus bone.	Safety shoe design, foot rest design.
36.	Grip diameter (Outside)	The distance between the joint of the 1st and 2nd phalanges of the thumb and knuckles of the middle finger measured with the hand to the grip of a cane.	Handle design, control grip design, clearance for maintenance purpose.
37.	Grip span	The maximum distance between the palm and the tip of middle finger when fingers are in grip position.	Design of hand tools, design of sprayer lid diameter, design of horticultural tools like secateurs, scissor.
38.	Grip diameter (Inside)	The diameter of the widest level of a cone which the subject can grasp with his thumb and middle finger touching each other.	Handle design, control grip design, hand tool design.
39.	Middle finger palm grip dia	The diameter of the widest level of the cylinder which the subject can grasp with his palm and middle finger touching each other.	Handle design, control grip design, hand tool design.
40.	Maximum Grip Length	The maximum length between the tip of the index finger and the tip of the thumb while the palm, thumb and fingers are in grip position.	Handle design, control grip design, lid design of sprayer containers, control panel design.
41.	Index finger	The diameter of the index finger of the right	Design of controls,

	diameter	hand measured at the joint of the 1st and 2nd phalanges of the index finger.	push button design.
42.	Biacromial breadth	The transverse distance across the shoulder from right to left acromion. The subject stands erect andlooks straight forward.	General body description, workplace layout, handles design, body linkages.
43.	Bideltoid breadth	The horizontal distance across the maximum lateral protrusion of the right and left deltoid muscles. The subject stands erect and looks straight forward	General body description workplace layout door width, handle design, body linkages, access opening.
44.	Chest breadth	The breadth of the torso measured at the nipple level. The subject stands erect and looks straight forward.	General body description, workplace layout, handle design, deciding width of front mounted equipment.
45.	Chest depth	The maximum depth of the torso measured at the nipple level. The subject stands erect and looks forward.	General body description, personal protective clothing design.
46.	Interscye breadth	The distance across the back between the posterior axillary folds at lower level of the armpit.	Body linkages, crutch design, knapsack design, deciding width of knapsack equipment.
47.	Waist breadth	The breadth of the torso at the waist level. The subject stands erect and looks straight forward.	Seat design, workplace layout personal protective clothing design.
48.	Hip breadth	The maximum breadth of the lower torso. The subject stands erect and looks straight forward.	General body description, seat design workplace layout.
49.	Foot length	The length of the measured parallel to its long axis.	General body description comparison of different populations. Body linkages, foot control design, pedal design, and workplace layout safety shoe design.
50.	Instep length	The distance from the plane of the heel to the point of maximum medial protuberance	Safety shoe design, foot rest design, foot

		of the foot.	control design specially brake, clutch and accelerator pedals.
51.	Foot breadth (Ball of the foot)	The maximum breadth of the foot as measured at right angles to its long axis.	Width of foot controls, pedal design like brake, clutch and accelerator pedals, workplace layout.
52.	Heel breadth	The maximum breadth of the heel as measured below the projection of the ankle bones	Foot rest design safety shoe design, pedal design, workplace layout.
53.	Head length	The maximum length of the head as measured from glabella to the back of the head.	Safety head design, cap design.
54.	Head breadth	The maximum breadth of the head	Safety head gear design, cap design.
55.	Menton to top of the head	The distance from the lower edge of the tip of chin to the level of the vertex of the head	Safety head gear design (helmet), protection head cover for face during spraying operation and for protection against honey bees.
56.	Biceps skin fold	The thickness of skin fold picked up parallel to the arm on the bicep between the acromion and the elbow.	Comparison of populations, determination of lean body mass, estimate of body fat.
57.	Subscapular skin fold	The thickness of the skin fold picked up just the inferior angle of the fight scapula and parallel to the tension lines of the skin.	Comparison of populations, determination of lean body mass, estimate of body fat.
58.	Supra iliac skin fold	The thickness of the skin fold picked up in the mid axillary line at the level of the crest of the illium.	Comparison of populations, determination of lean body mass, estimate of body fat.
59.	Triceps skin fold	The thickness of skin fold on the back of the arm halfway between acromion and the tip of the elbow picked up parallel to the long axis of the upper arm.	Comparison of populations, determination of lean body mass, estimation of body fat.
60.	Sitting height	The height from the sitting surface to the vertex of the head. The subject sits erect and looks straight forward.	General body description control panel layout, work

			place layout.
61.	Vertical grip reach sitting	The vertical distance from the standing surface to the height of the pointer held horizontal to the subjects' fist when the arm is maximally extended upward. The subject stands erect andlooks straight forward.	Workplace layout, design of controls.
62.	Sitting eye height	The height from the sitting surface to the external canthus. The subject sits erect and looks straight forward.	Display and control panel design, seat design and visual field determination.
63.	Sitting acromion height	The height from the sitting surface to the top of the acromion. The subject sits erect and looks straight forward.	Body linkages, control panel layout, workplace layout, hand reach envelopes, seat design.
64.	Thigh clearance height sitting	The height of the highest point of the thigh above the sitting surface. The subject sits erect ad looks straight forward.	General body description, workplace layout, seat design, clearance between seat and steering wheel, sitting surface and inner table height.
65.	Elbow rest height	The height of the bottom of the tip of the elbow above the sitting surface.	Seat handle design, control design, control panel design, work space layout.
66.	Popliteal Sitting height	The height of the underside of the upper leg above the footrest surface. The subject sits erect and looks straight forward.	General body description, seat design, design of chairs and stools, height of seating surface, workplace layout.
67.	Knee height sitting	The height from the footrest surface of the musculature just above the knee. The subject sits erect and looks straight forward.	Work place layout, seat design, general body description.
68.	Functional leg length	The distance from the back at the waist level to the heel, measured along the long axis of erect on the edge of a chair, leg extended forward with his knee straightened.	Comparison of population, foot pedal design, leg control design biomechanics study.
69.	Coronoid fossa to hand length	The distance from the tip of the middle finger to the coronoid fossa with arms bend at 90^0 with the upper arm.	Control panel design, thresher feeding chute design, chaff cutter feeding chute design.

70.	Abdominal depth sitting	The distance from the rear most surface of the waist to the front of the umbilicus.	Seat design, work place layout, and clearance space for steering /other controls/work surfaces.
71.	Buttock knee length	The horizontal distance from the rear most surface of the buttock to the front of the knee cap.	Body linkages, seat design, work place layout, horizontal clearance between seat and work surface, biomechanics study.
72.	Buttock popliteal length	The horizontal distance from the rear most surface of the buttock to the back of the lower cap.	Body linkages, seat depth design, work place layout biomechanics study.
73.	Thumb tip reach	The distance from the wall to the tip of the thumb measured with the shoulder against the wall arm extended forward and index finger touching the tip of the thumb.	Control panel design, work place layout.
74.	Shoulder grip length	The horizontal distance from a pointer held in the subjects' fist to a wall against which he/she stands, measured with the arms extended horizontally.	Body linkages, control panel design, work place layout, reach envelops, biomechanics study.
75.	Elbow grip length	The distance from the tip of the bent elbow to the corner of the clenched fist.	Body linkages, control panel design, work place layout, biomechanics study.
76.	Forearm hand length	The distance from the tip of the elbow to the top of the middle finger measured along the long axis of the arm.	Control panel design, biomechanics study, handle design, feeding chutes of threshers and chaff cutter.
77.	Hip breadth sitting	The breadth of the body as measured across the widest portion of the hips. The subject sits erect looking straight forward.	General body description, seat width design, workplace layout.
78.	Elbow-elbow breadth sitting	The distance across the lateral surfaces of the elbows flexed at 90^0 with the upper arm and resting lightly against the body.	Body linkages, seat arm rest design, seat design, clearance in workplace, handle width in manually operated equipment.
79.	Knee-knee breadth	The maximum horizontal distance across the lateral surfaces of the knees gently touching.	Comparison of different populations, work

			place design, general body description.
80.	Hand grip strength (right)	The grip strength of the right hand measured with handgrip dynamometer when the subject stands erect with his arms hanging downwards.	Design of hand control lever hand clutch, hand brake, sprayer trigger.
81.	Hand grip strength (Left)	The grip strength of the left hand measured with handgrip dynamometer when the subject stands erect with his arms hanging downwards.	Design of hand control lever hand clutch, hand brake, sprayer trigger.
82.	Push strength both hands in standing posture	The maximum push force applied with both hands on load cell in standing posture on the strength measured set up with left leg forward, bent at knee and right leg backward, straight.	Design of manually operated equipment like wheel hoe, cono weeder, lawn mower, manual harvester, hanging type cleaner, push carts, material hanging equipment.
83.	Pull strength both hands in standing	The maximum pull force applied with both hands on load cell in standing posture on the strength measurement setup with left leg forward, straight and right leg backward bent at knee.	Design of manually operated equipment like wheel hoe, lawn mower, hand ridger, long handled hoes, rice transplanter, rice drum seeder, seed drill, material handling equipment.
84.	Right hand pull strength in sitting	The maximum pull force applied with right hand on load cell in sitting posture on the strength measurement set up in horizontal plane at sea height.	Design of gear shift lever, handle lever, various pull type controls in control panel.
85.	Left hand pull strength in sitting	The maximum pull force applied with left hand on load cell in sitting posture on the strength measurement set up in horizontal plane at seat height.	Design of gear shift lever, handle lever, parking brake, various pull type controls in control panel.
86.	Right hand push strength in sitting	The maximum push force applied with right hand on load cell in sitting posture on the strength measurement set up in horizontal plane at seat height.	Design of gear shift lever, handle lever, position control and draft control levers on tractor, various push type controls in control panel.
87.	Left hand push strength in sitting	The maximum push force applied with left hand on load cell in sitting posture on the strength measurement set up in horizontal plane at seat height.	Design of gear shift lever, handle lever, PTO lever, high-low speed lever, various

			push type controls in control panel.
88.	Max right leg strength in sitting	The maximum force applied by the right leg on load cell in erect sitting posture on the strength measurement set up with knee flexed at angle between 90^0 -110^0 . The horizontal distance of the pedal being 45% of stature from SRP and vertical distance being 19% of stature from SRP.	Design of leg-operated controls like brake pedal, differential lock, other pedal operated machines as sewing machine, pedal operated thresher, pedal operated cleaner grader.
89.	Maximum left leg strength in sitting	The maximum force applied by the left leg on load cell in erect sitting posture on the strength measurement set up with knee flexed at angle between 90^0 -110^0 . The horizontal distance of the pedal being 45% of stature from SRP and vertical distance being 19% of stature from SRP.	Design of leg-operated controls like brake pedal, differential lock, other pedal operated machines as sewing machine, pedal operated thresher, pedal operated cleaner grader.
90.	Max right foot strength in sitting	The maximum force applied by the right foot on load cell, keeping the heel on the ground as fulcrum, in erect sitting posture on the strength measurement set up with knee flexed at angle between 90^0-110^0.	Design of accelerator pedal and other foot operated controls.
91.	Maximum left foot strength in sitting	The maximum force applied by the left foot on load cell, keeping the heel on the ground as fulcrum in erect sitting posture on the strength measurement set up with knee flexed at angle between 90^0-110^0.	Design of accelerator pedal and other foot operated controls
92.	Torque strength of preferred hand in standing	The maximum torque applied by the preferred hand in vertical plane on the crank of the strength measurement set up in standing posture, looking straight with right leg forward, bent at knee and left leg backward straight for right handed subjects. Position of the legs vice versa in case of left handed subjects.	Design of manually operated equipment like chaff cutter, sugarcane crusher, rotary maize sheller, hand winnower and other equipment operated by hand in rotary mode.
93.	Torque strength of both hand in standing	The maximum torque applied by both hands in vertical plane on the crank of the strength measurement set up in standing posture, looking straight with left leg forward, bent at knee and right leg backward, straight.	Design of manually operated equipment like chaff cutter, sugarcane crusher, rotary maize sheller, hand winnower and other equipment operated by hand in rotary mode.
94.	Torque strength of both hands in sitting	The maximum torque applied by both hands in clockwise direction on the steering wheel with load cell attached tangentially to the steering wheel in erect sitting posture on the strength measurement set up.	Design of wheel type controls like steering wheel.
95.	Hand grip torque	The maximum grip torque applied by preferred hand in anticlockwise direction on the centre grip of the steering wheel with load cell attached tangentially to the steering wheel in erect sitting posture.	Design of knob controls, sprayer and fuel tank lids, opening cover of service point.

Roebuck et al. (1975) quoted to design engineering anthropometry. It is concerned with the physical measurements of human body required mainly to develop the basic engineering standards, set specific requirements and desire suitability of any manufactured product intended for the human consumer. Gite et al. (2009) collected anthropometric data of agricultural workers and compiled the data on all India, Arunachal Pradesh, Gujarat, Jammu & Kashmir, Madhya Pradesh, Maharashtra, Meghalaya, Mizoram, Orissa, Punjab, Tamil Nadu, Uttar Pradesh and West Bengal. They suggested the use of data for design of farm machinery on the basis of 5th, 50th and 95th percentile values of the dimensions (Table.10.2).

Table. 10.2 Mean anthropometric and strength data of Male and Female Indian Agricultural Workers

		Male			Female	
	95th	Mean	5th	95th	Mean	5th
Weight (Kg)	68.9	54.7	40.4	59.1	46.3	33.55
Stature	1774	1633	1521	1615	1515	1414
Acromial height	1468	1362	1248	1353	1261	1196
Arm reach from the wall	921	838	756	848	773	681
Bi-acromial breadth	402	330	364	340	292	243
Bideltoid breadth	471	416	361	423	371	318
Calf circumference	367	312	310	353	292	230
Chest circumference	944	845	746	934	813	693
Chest depth	243	208	173	259	207	154
Coronoid fossa to hand length	439	392	345	400	357	314
Elbow- elbow breadth sitting	452	375	297	413	350	286
Elbow height	1115	1027	938	1037	960	883
Elbow rest height	266	214	162	259	208	158
Eye height	1636	1522	1409	1504	1403	1302
Foot breadth (ball of foot)	110	94	78	101	89	76
Foot length	269	245	221	243	227	212
Forearm hand length	503	453	408	462	417	378
Hand length	197	178	160	182	167	151

Head breadth	171	148	125	202	142	156
head length	205	185	166	202	179	156
Hip breadth sitting	364	311	258	355	302	249
Instep length	208	184	142	191	167	149
Knee height	530	472	415	488	438	388
Medial malleous height	96	80	63	92	74	56
Menton to top of the head	246	213	179	232	197	162
Metacarpal-III height	763	690	616	718	649	581
Olecranon height	1085	999	913	1011	936	861
Popliteal height sitting	468	417	367	441	391	342
Sitting Acromial height	645	568	492	597	529	461
Sitting eye height	812	726	640	743	771	599
Sitting height	916	830	744	847	775	702
Span	1832	1697	1562	1680	1551	1422
Span Akimbo	964	872	780	872	790	707
Trochanteric height	925	814	703	842	777	695
Vertical reach	2237	2080	1923	2063	1921	1778
Waist back length	510	443	375	447	385	367
Waist circumference	901	765	629	858	720	582

(Source:Gite, 2009)

Lesson 11. ARRANGEMENT AND UTILIZATION OF WORK SPACE, ATMOSPHERE CONDITION

11.1. Introduction

Human workspace can consist of many different physical situations including that of the plumber working under a stoped up sink, the astronaut in his capsule, the assembler at his position on the assembly line, the flagpole painter and the minister in his pulpit. There are millions of peoples whose work activities are carried out while seated in a fixed location. The space with in which such an individual works is sometimes referred to as the 'work-space envelop'. This envelop should be designed on a situational basis, considering the particular activities to be performed and the types of people who are to use the space. To illustrate the types of data that would be relevant in designing specific work space envelop, however, the results of a couple of anthropometric studies will be shown.

11.1.2 Workplace and Workspace

Most workers spend a major portion of their time in a small work area, called the work space or 'work envelop'. A work space is a three dimensional region surrounding the worker, define by the outmost points touched by various parts of the body and by the controls, tools or other equipment used by the worker. The term workplace is more comprehensive and can be as varied as assembly stations, offices, warehouses, vehicle cabs or any other area where work is performed.

11.2 Arrangement and utilization of work space:

The area for potential regulations affecting operator work space designs which is Minimum dimensions based on normal operational requirements. If the driver is to safely operate his vehicle he must first be able to fit into the cab without being forced into awkward postures. He must then be able to reach and operate all controls without undue hindrance. In essence this means that the cab needs to be designed around the operator. While we are primarily talking about minimum dimensions, it is important to note that male and female maximum dimensions must also be considered when designing for the smaller drivers.

The design dimensions of the cab interior workspace can have an impact on driver comfort and safety. If the driver has to assume cramped or awkward postures due to inadequate space, he may tend to fatigue more quickly. If there is insufficient room to operate steering wheel, foot pedals and other controls, the driver may not perform at his best. Regulations for the cab's interior should require designs which ensure a minimum safety, health, and comfort level and which reduce the severity of the deterioration in the driver's performance capability over time. A reduction in the driver's allotted space in the cab is certainly a trend in the wrong direction to achieve these objectives.

11.2.1 Factors considered in operator workplace design

Multiple factors are to be considered in operator workplace design (OWPD) on which review of literature is citied and has been presented under following heads:

1. Ergonomics in agricultural operations
2. Anthropometry in agricultural machines
3. Optimization of operator workplace
4. OWPD in relation to seat
5. OWPD in relation to steering wheel
6. Driver’s response
7. Operating posture
8. Control locations

11.2.2 Workplace layout

Proper workplace lay out requires that consideration be given to various workplace dimensions. The control and the operation being controlled must be located with due regard to :

1. The operator size
2. His position and the direction in which he can most easily look
3. The spaces in which he can best manipulate controls
4. Special influences such as protective clothing.

11.2.3. Determining the operation which the operator is controlling

Before beginning to design the workplace it is necessary to obtain preliminary information about the man-machine system. According to the nature and extent of the project a decision will have to be made on the degree of formality that is required at this stage.

11.2.4. Placing the operator so he can have optimum vision, or vision of the display

In order to plan the sensory input to the operator the principal consideration is normally to place the operator so that he can have optimum vision of the display. Where the operator is in direct control this may be the comparatively straightforward examination of the visual aspects of the task as here described.

Safety, comfort and convenience should be considered in the design, location and construction of the operator’s work place. The work place should be located on the machine so that visibility in the driving position is good without requiring the operator to work in an awkward, tiring position. Levers, pedals and instruments should be conveniently and logically located and the work place should fit both tall and short operators. In addition, the operator should be able to change his working position easily and the work area should be free of sharp edges and obstructions such as transmission cases.

Functional considerations in design of the workplace for an off-road vehicle operator are visibility, easy access to controls, and clearance. Easy access to all controls in the workplace and cab are necessary so the operator can achieve the desired machine performance and productivity. Primary visibility requires that the operator can look outside the cab in any direction, both near and far. Secondary visibility is needed to monitor instruments and controls in the workplace and cab. Clearance at various locations is necessary to provide access to and from the workplace. Proper workplace dimensions in relation to the seat are important for ease in grasping and operating controls. These factors are related to the operator's anthropometric and biomechanical characteristics

To provide a reasonably satisfactory posture whilst driving, the limb angles should be within certain specified ranges as given in Table 11.1

Table 11.1- Range of comfort angle

S.No.	Body member	Angle (in Degrees)
1	Back	20-30
2	Hips	95-120
3	Knee	95-135
4	Ankle	90-110
5	Upper Arm	10-45
6	Elbow	80-120
7	Wrist	170-196

(Source: Yadav and Tiwari, 1998)

Table 11.2 - Optimum movement range for a seated operator ("b" is derived value)

S.No.	Body Member	Movement Range (in degrees)	Comfort Range (in degrees)	Comments
1	Back	-	10-45	-
2	Hips	80-226[b]	95-120	95-97° for alert driving
3	Knee	53-180[b]	95-135	110-120° for pedal operation
4	Ankle	55-128[b]	90-100	-

5	Upper Arm	55-179[b]	10-45	For operation of steering
6	Elbow	38-180[b]	80-120	For seated work
7	Wrist	126-277[b]	-	-

(Source: Yadav and Tiwari, 1998)

11.3. Operating posture

A sitting posture which results in the nearest approximation to the "normal" lumbar shape is one in which the trunk-thigh angle is about 115° and the lumbar position of the spine is supported (Keegan and Radke, 1964). Babbs (1977) described a systematic layout to define the seating package and body reference points in vehicle design, as well as to determine the adjustment envelope required to fit a range of sizes from a given population. He arranged all the body joint angles according to their suitability within the comfort range (Fig. 11.1). The optimum and maximum areas, for toe-operated and heel-operated controls, were delineated on the basis of dynamic anthropometric data. The maximum areas indicated require a fair amount of thigh or leg movement or both.

Anthropometric data of the user population are only used for proper design of the operator workplace to meet visibility and clearance requirements. Safety comfort and convenience must be considered in the design, location and construction of the operator workplace Hansson *et al.* (1970). Tractor operator controls within the workplace should be conveniently and logically located and the workplace should fit both tall and short operators. The seat should be designed so that, in both the forward and backward sitting postures, it provides support to the upper edge of the pelvis in order to assist rotation. To accommodate tractor operators ranging from the 5th to 95th percentile, it is easier to adjust the seat than to adjust controls; however, there must be a few compromises between hand and foot controls. The height of the seat cannot be changed greatly since, for a small person a higher seat would result in a worsened foot-pedal relationship. It is easy to provide horizontal seat adjustment with few design changes Grandjean (1988)

Research on the human – tractor interface for tractor-operator enclosures can be traced back to the 1950s in Sweden (Moberg 1973). At that time, there were a number of fatal incidents involving tractor overturns; these incidents caused strong public reaction and especial concerns among the Swedish trade organizations. In response to these concerns, researchers developed test procedures to ensure the mechanical soundness of tractor cabs and protection frames. Subsequently, researchers developed a set of the dimensions for the operator protection zone, mainly in order to simplify the mechanical test work and to minimize variations in mechanical test results. More recent design parameters – impediment of steering wheel, hand controls and protection frames for tractor drivers – were not specifically examined at that time.

11.4. The operator space envelope dimensions

The operator space envelope dimensions as per SAE J154 are discussed in this section. This defines dimensions for the minimum normal operating space envelope around the operator for operator enclosures (cabs, ROPS) on off-road machines.

(i)The dimensions for the recommended minimum normal operating space envelope around a clothed operator are defined for a seated operator in Fig. 11.1 and for a standing operator in Fig. 11.2

(iii) The operator enclosure minimum space envelope may be smaller than specified in Fig. 11.1 and Fig. 11.2 if it can be demonstrated that the reduced operator space envelope for a particular machine application allows for adequate operator performance. Potential modifications for the operator enclosure space envelope include, but are not limited to:

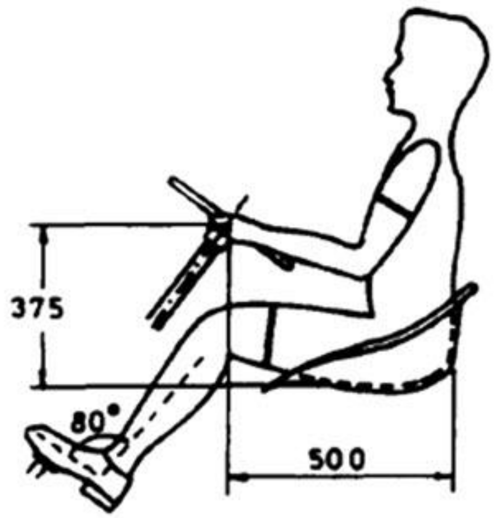


Fig.11.1: Physiologically favourable position of upper body and arms when handling tractor steering wheel (all dimensions in millimeters)

Some particular types of machines may necessitate use of an operator space envelope smaller than the minimum recommended by this document. For these machines, the internal operator space envelope width may be reduced to a minimum of 670 mm to accommodate a 95th percentile operator with heavy clothing. If machine width constraints necessitate a space envelope width less than 670 mm, the space envelope may not accommodate a 95th

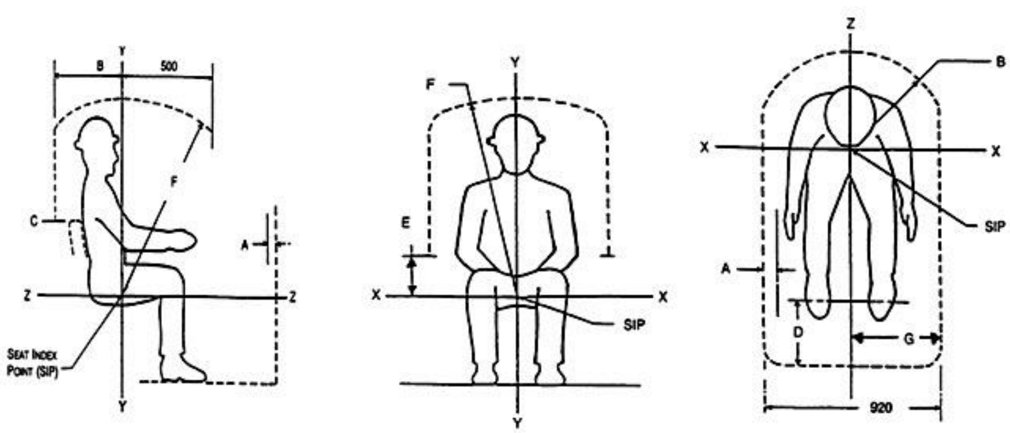


Fig. 11.2: Minimum operator space envelope dimensions for sitting enclosure (All dimensions in millimeters)

percentile operator with heavy clothing and the operator should be alerted that the machine may not accommodate large operators. All operators should check the space envelope width before operating the machine to insure that it is adequate.

Human body never stretches to its full arm reach limits, it can stretch to only 80% of its reach limit, at which it would be in comfort zone for operating any control. Thus, the dimensions of the cabin are ample and roomy enough to accommodate every class of operator taken under consideration. But clearance towards the rear of the seat is a prime necessity for tractor having back hoe and fitted with a swivel seat to change position and operate the controls located on the rear-end for the back hoe. Since there are very rare tractors in India with back hoe so the clearance towards the rear is relatively irrelevant from utility point of view. Even then, the clearance is enough for each and every operator. There is ample of space for leg travel towards the foot operated controls (clutch, brake and accelerator) and no operator should find any difficulty regarding this matter. Everyone should be comfortable in operating these controls with ease and would not be strained at all.

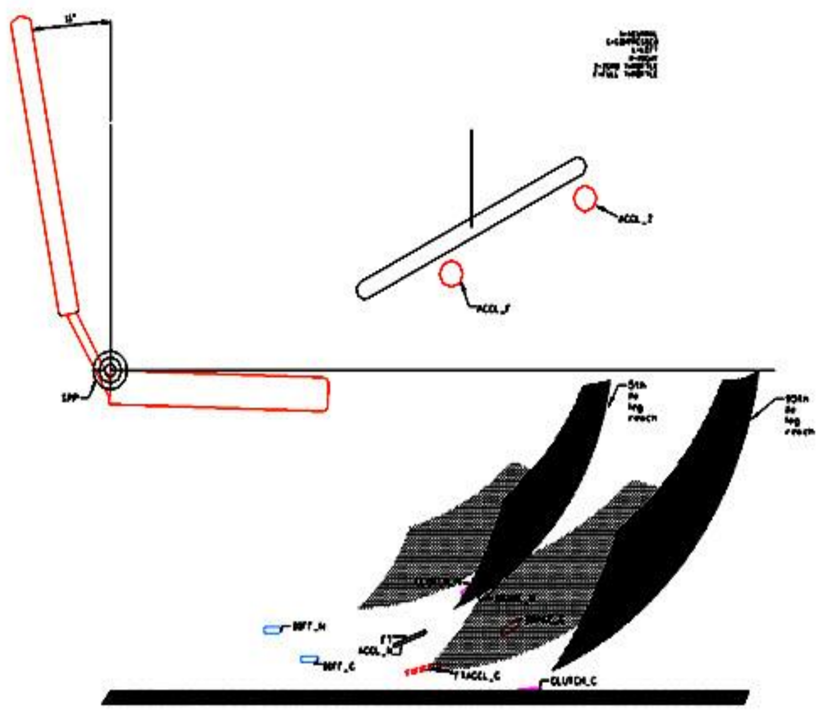


Fig. 11.3 Location of some of leg controls on a tractor (seat at front) with 5th and 95th percentile leg reach envelope of male operators

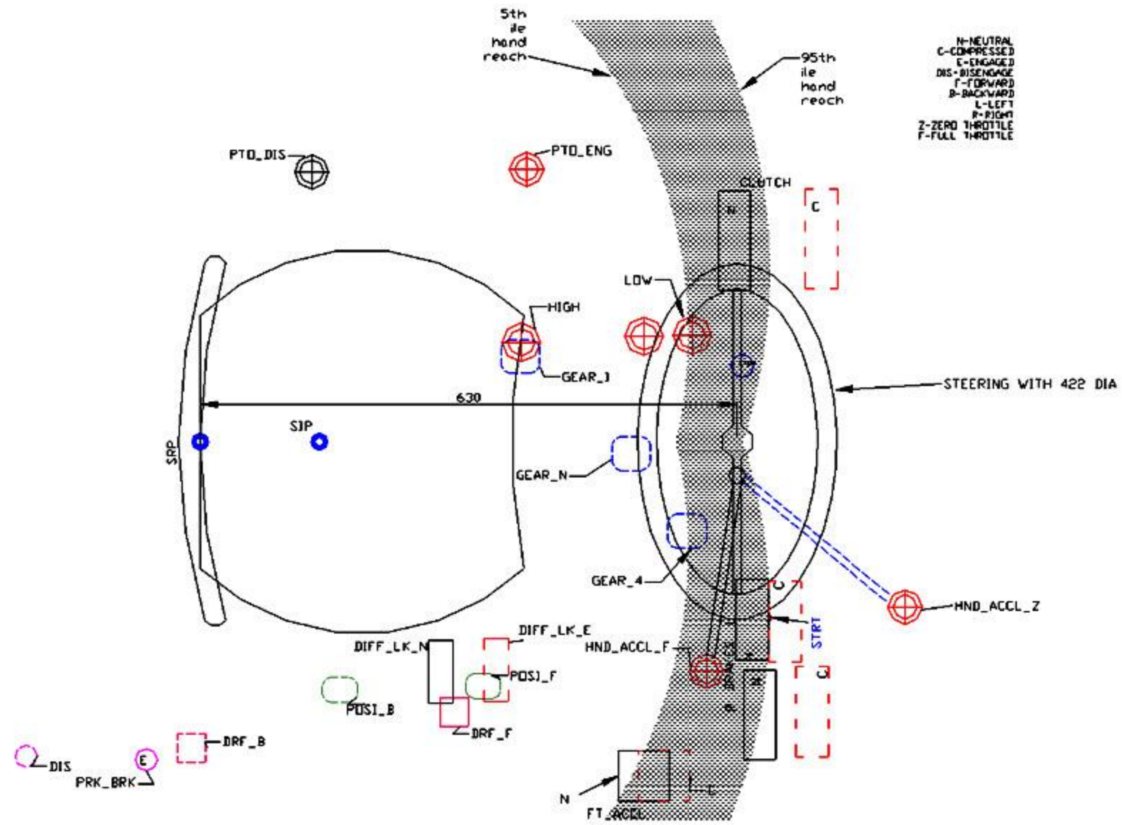


Fig. 11.4. Location of controls on the tractor (seat at front) with hand reach envelopes for 5th and 95th percentile of male operators

11.4.1 Spatial, Visual, and Control Requirements of the Operator

Functional considerations in design of the workplace for an off-road vehicle operator are visibility, easy access to controls, and clearance. Easy access to all controls in the workplace and cab are necessary so the operator can achieve the desired machine performance and productivity. Primary visibility requires that the operator can look outside the cab in any direction, both near and far. Secondary visibility is needed to monitor instruments and controls in the workplace and cab. Clearance at various locations is necessary to provide access to and from the workplace. Proper workplace dimensions in relation to the seat are important for ease in grasping and operating controls. These factors are related to the operator's anthropometric and biomechanical characteristics.

11.5. Atmosphere condition

Off-road vehicles are used under varied geographic and climatic conditions. Direct exposure to temperature, humidity, wind, thermal radiation, dust, and chemicals is encountered. Table 11.3 defines comfort and bearable zones for four of these parameters as they apply to humans. Temperature, humidity, ventilation, and thermal radiation zones are interrelated.

11.5.1Climate

The indoor climate needs to satisfy several conditions if work is to be carried out in comfort. Four climatic factors (air temperature, radiation temperature of cold and hot surfaces, air velocity, and relative humidity) are significant in this respect.

Table 11.3. Environmental zones for selected parameters.

Environmental Parameter	Comfort Zone		Bearable zone	
	Lower Limit	Upper limit	Lower Limit	Upper limit
Temperature, ^{o}C	18	24	-1.0	38
Humidity, % RH	30	70	10	90
Ventillation, m3/mm	00.37	00.57	00.14	00.14

(Source: Sharma and Mukesh, 2010)

Design of an operator enclosure for a tractor should include thermal comfort, ride comfort, noise protection, air quality, and rollover protection.

11.5.2 Dry-Bulb Temperature

In many homes, it is common to see a thermometer placed on the wall of the entrance hall or living room. Most people are familiar with these mercury-in-glass thermometers and their use in measuring the temperature of the air. Although dry-bulb temperature indicates the thermal state of the air, other factors have an equally important effect on the heat gained or lost by a worker.

11.5.3 Relative Humidity and Wet-Bulb Temperature

One of the most important factors is the humidity or water vapour content of the air. At all temperatures above freezing, water tends to evaporate into the air, and the rate of evaporation increase with temperature. “Relative humidity” is a term used to describe the water vapour pressure of the air at a given temperature. It is the water vapour pressure at a given temperature expressed as a percentage of the saturated water vapour pressure at the temperature.

It is common in ergonomics to take three separate measurements of the air temperature. The wet-bulb temperature depends not only on the dry-bulb temperature but also on the relative humidity of the air. The wet-bulb and dry-bulb temperature can be used to calculate the relative humidity. This calculation is normally done using psychometric charts.

11.5.4 Globe Temperature

Another important measurement of temperature accounts for the effects of radiant heat. It is known as globe temperature. Traditionally, the bulb of a mercury-in-glass thermometer is placed in a metal sphere which is painted matte black. In many situations, measurements of globe temperature are essential if the true nature of the thermal environment is to be evaluated.

11.6 Thermal Comfort in Operator Enclosures

Thermal comfort is defined as the state of mind that expresses satisfaction with the thermal environment. Operator enclosure design must include cab pressurization, air filtration, air movement, heating, cooling, and window defrosting. These factors must be considered in order to provide environmentally clean air with proper air velocity and direction, temperature, and humidity for acceptable human thermal comfort. Design values suggested by Zitko (1977) provide basic guidelines for heating, cooling, air movement, cab pressurization, and air filter properties and are shown in Table 11.4.

Table 11.4. Design parameters for thermal comfort in an operator enclosure.

Parameter	Rating or Capacity
Heating	8.2 kW at 66°C and water flow 11.4 L/m
Cooling	7.0 kW at 32°C and 60% relative humidity
Air movement	Three-speed blower rated at 0.236 m3/s at 50 Pa
Cab pressurization	50 to 100 Pa above outside of cab
Fresh air filter	1.92 m2 pleated paper, self-cleaning

(Source: Zitko, R.F. 1977.)

11.6.1 Illumination/ Light

Light is that part of the electromagnetic spectrum which will stimulate a response in the receptors of the eye. It frequency which is usually expressed a wavelength, determines the colour of a light and its amplitude determines its intensity. The light intensity, for instance, the amount of light which falls on the work surface, must be sufficiently high whenever visual tasks have to be carried out rapidly, and with precision and ease. Apart from light intensity, differences in luminance (contrast) in the visual field are also important. Luminance is the amount of light reflected back to the eyes from the surface of objects in the visual field. Light intensity is expressed in lux, and luminance (brightness) in candela per m2 (cdm 2).

11.6.2 Air Movement and Wind Chill

In an evaluation of the effects of temperature on the worker, it is important to take air movement into account. Air movement moderates the effects of high temperatures and exacerbates the problems of low temperatures. Air movement can be measured using mechanical anemometers (in which the rate of rotation of a vane is proportional to the velocity of the air flowing through it) or by electrical means such as the hot-wire anemometer, where air movement cools a heated wire.

Avoid very humid and very dry air

Humid air (relative humidity in excess of 70 per cent) or dry air (relative humidity less than 30 per cent) can affect thermal comfort. Dry air can lead to irritation of eyes and mucous membranes, and also increases the possibility of static electricity (risk of inflammation or ignition of chemical substances, unpleasant shocks, equipment failure). The humidity can be controlled either by adding moisture to the air or by removing it.

11.6.3 Heat Stress

Heat stress may be defined as the combination of all those factors both climatic and non-climatic which lead to convective or radiant heat gains by the body or prevent heat dissipation from the body. Modern heat stress monitors make use of thermistors instead or mercury-in-glass thermometers. These devices often provide combined measurements of temperature known as heat stress indexes. The wet-bulb globe temperature (WBGT) is a commonly used heat stress index. Commercial heat stress monitors calculate the WBGT index as follows:

$$\text{WBGT (outdoors)} = 0.7\ \text{WB} + 0.2\ \text{GT} + 0.1\ \text{DB}$$

$$\text{WBGT (indoors)} = 0.7\ \text{WB} + 0.3\ \text{GT}$$

It should be noted that the calculation of the index of heat stress depends very heavily on the wet-bulb temperature. This fact also demonstrates why simple measurements of dry-bulb temperature alone cannot provide an accurate measure of the stress involved in working in a hot environment.

Avoid hot or cold radiating surfaces

Hot surfaces such as a roof and cold surfaces such as a cold window can affect thermal comfort. Steps must be taken whenever the radiant temperature of these surfaces differs by more than four degrees from the air temperature.

Avoid extremely hot and cold climates

Exposed parts of the skin can reach the threshold of pain in extremely hot climates or near very hot radiating surfaces. In a very cold climate, the hazard is frost-bite, the risk of which increases at high air speeds.

Effects of climate performance

Climate has a profound effect on the performance of physical tasks. It can also affect mental task performance, but this effect is thought to be indirect and due to the effects of climate on physiological variables, which themselves affect performance. There are two main theories concerning the effects of climate on performance. Climate extremes can increase the arousal level, whereas overly comfortable conditions can lower it (Meese et al., 1989). A competing theory suggests that climate extremes, particularly cold, have a distracting effect performance declines because of momentary shifts of attention away from the task toward the environment.

Lesson 12. HEAT EXCHANGE PROCESS AND PERFORMANCE, AIR POLLUTION

12.1 Introduction

To study the subject of heat exchange, one should familiar with the some common terminologies.

Evaporation

Evaporation is the method of body heat transmission to the environment by evaporation of perspiration and respiration. Evaporation can only result in a transfer of heat from the body to the environment. Sweat must be evaporated from the skin surface for the heat transfer to occur. In saturated environments (RH=100%), no heat transfer can take place through evaporation

Convection

Convection is the method of heat exchange through a fluid medium viz. air, water. Generally the convection heat transfer is made by air or fluid through movement of its molecules. The air/ fluid molecules are warmed up by touching the environment, in turn, absorb heat from the warmer air/ fluid molecules. This process is called natural or free convection.

Conduction

Conduction is the method of heat exchange by direct contact of the body with other objects, in this method, heat is transferred from one substance to another, or among molecules within a substance, without physical movement of the substance itself or its molecules. Since clothing insulates the body, the amount of heat exchange in the body is usually minimal and is often ignored in heat balance equation.

Radiation

Generally any substance with a temperature above absolute zero emits heat radiation in the form of electromagnetic waves (similar to light waves). Thermal radiation will travel through vacuum or transparent media. The amount of heat radiated depends on the temperature and area of the radiating object, regardless of its mass.

Latent heat

Latent heat is the amount of heat that must be absorbed when a substance changes phase from solid to liquid or from liquid to gas, or the amount of heat lost (emitted) during phase changes from gas to liquid or from liquid to solid.

Radiation Heat Load

Radiant heat exchange occurs between the occupant and its surroundings. During vehicle cool down and warm-up processes, the radiation heat load has roughly the same influence as air temperature on occupant thermal comfort. The current human physiology model can simulate an arbitrary number of body segments. Each of these segments consists of four body layers (core, muscle, fat, and skin tissues) and a clothing layer. A separate series of nodes, representing the arteries and veins, provide for convective heat transfer between segments and tissue nodes and the counter current heat exchange between the arteries and the veins. Human body thermal regulation is mainly achieved by regulating blood flow, so a realistic blood flow model is important for any dynamic model of human thermal comfort. The body uses vasoconstriction and vasodilatation to regulate blood distribution in order to control skin temperature through an increase or decrease of heat loss to the environment. Veins and arteries are paired, even down to very small vessels, and veins carry heat from the arteries back to the core. The model is able to predict both core and extremity skin temperatures with reasonable accuracy under a range of environmental conditions. The validations for transient conditions are;

1. Clothing Model :

2. Contact surfaces:

3. Physiological variation:

1. Clothing Model: Heat capacity of the clothing is important when considering transient effects. Moisture capacitance is important to correctly model evaporative heat loss from the body through clothing. The moisture model uses the regain approach to calculate the amount of moisture that a specific fabric will absorb at a given relative humidity.

2. Contact surfaces: In almost any environment, the body is in contact with solid surfaces and loses or gains heat via heat conduction. In the vehicle, the seat contacts a considerable fraction of the body and must be considered to accurately model the occupant. The thermal properties of the contact surface are used to simulate its surface temperature. Each body segment includes the fractions of exposed skin and clothed skin in contact with the surface.

3. Physiological variation: Human physiology varies significantly among individuals, and these differences can affect perceptions of thermal comfort; e.g., higher metabolic rate or increased body fat can cause people to feel warmer.

Sweating

Humans have about 1.6 million high-capacity (eccrine) sweat glands in their skin. This is why humans can lose about 500 grams of sweat per square meter of skin, whereas horses and camels can lose only 100 and 240 g, respectively.

Sweat which is produced by the eccrine glands in the skin consists mainly of water. It is a dilute solution of various electrolytes, principally sodium, potassium and chloride. Passive diffusion of water through the sweat glands. However in humid environments, evaporation of sweat diminishes and cooling efficiency is lost even though sweat continues to be produced.

Profuse sweating has two important disadvantages:

- Dehydration may occur if more water is lost than is replaced.
- Salt may be lost.

The adrencortical hormone, aldosterone, is involved in the conservation of sodium, causing it to be actively reabsorbed in the sweat glands and in the kidneys. As the rate of sweat production increases, less sodium ions can be reabsorbed.

Shivering

Involuntary shivering is a thermoregulatory mechanism involving active heat production. Group of motor units act out of phase with one another and muscles act against their antagonists.

Voluntary movement also increases heat production but breaks up the insulating layers of air around the body, which increases the rate of heat loss. Both shivering and voluntary movement increase oxygen uptake and cardiac output and can lower a person's capacity to carry out physical work.

Work in Hot Climates

Heavy physical work in the heat imposes conflicting demands on the cardiovascular system. Cardiac capacity is a limiting factor placed under considerable strain when a person in working in the heat as output rises to meet the demands of both physical work and bodily cooling.

Heat Stroke

If a worker becomes dehydrated, sweat production diminishes and the deep body temperature may increase. Rapid elevations in body temperature increase the metabolic rate. If core temperature rises above 42^0 C, blood pressure may drop and insufficient blood is pumped to the vital organs, including the heart, kidney, and brain. rapid cooling of the body using cold sprays or wet sponges can be used to lower the temperature. Many industries take steps to prevent such dangerous situations from occurring as is described below.

Relative Humidity

Whether workers can tolerate a hot environment depends on several classes of variables. For example, dry-bulb temperature of more than 38^0 C can be tolerated if the relative humidity is less than 20 percent because at such low humidities the cooling efficiency of sweating is high.

Heat Acclimatization

Heat acclimatization is a physiological process of adaptation rather than a psychological adjustment to life in hot environment. It involves an increase in the capacity to produce sweat and a decrease in the core temperature threshold value for the initiation of sweating. Furthermore, acclimatization reduces the skin's blood-flow requirements, which reduces the cardiovascular load during work in the heat. Although the body can acclimatize to heat, it cannot acclimatize to dehydration. Fluid must be made available at all times even for acclimatized workers.

Physiological responses and heat exchange

When people are exposed to a hot environment, they experience first, vasodilatation (expansion of blood capillaries near the skin surface), which facilitates increased heat transfer from the core to the shell of the body to be removed by evaporation; and second , an activation of the sweat glands (in the subcutaneous layer under the skin) to facilitate evaporative heat loss (Astrand and Rodahi, 1986). At some level of heat load the limit of heat dissipation will be reached. Beyond this physiological limit the establishment of a steady state for the core temperature will become impossible, and it may increase to dangerous level. Furthermore the physiological limit is usually reached before the body temperature rises much above 40^{o}C (Poulton, 1970)

To prevent the internal heat build-up the body has to dissipate some of its metabolic heat. The body attempts to achieve thermal equilibrium with its surrounding environment through the following heat exchange methods: metabolism, evaporation, convection, conduction and radiation. The heat exchange follows the second law of thermodynamics, according to which heat from a substance of a higher temperature is transferred to another object with a lower temperature. The process of heat exchange between the body and its surrounding environment can be expressed by the heat balance equation:

$\pm S = M \pm CV \pm CD \pm R - E$

Where

S = heat storage (positive sign indicates heat gain, while negative indicates heat loss. If the heat balance is achieved, S =0);

M = metabolic heat (always positive)

CV = convective heat (positive sign indicates air temperature is higher than skin temperature and negative indicates a reversed case).

CD = conductive heat (positive when the contacting objects are warmer than skin and negative when the skin is warmer);

R = radiant heat (positive when surrounding objects are warmer than skin and negative when the skin is warmer);

E = evaporative heat (always negative).

Fundamentals of Human Thermoregulation

Human have a remarkably well-adapted ability to tolerate heat compared with other primates. This statement applies equally to Eskimos as to tropical rain forest dwellers despite their small differences.

Countercurrent Heat Exchange

Countercurrent heat exchange is essentially a method of conserving heat. It involves the exchange of heat between arteries and veins supplying the deep tissues. Arterial blood is precooled before it reaches the extremities and venous blood is warmed before it returns to the vital organs. An efficient heat-exchange system enables penguins for example, to spend long hours standing on ice at many degrees below freezing and to maintain a very high temperature gradient between their deep body tissues and the soles of their feet.

Effects of Heat on Performance

High internal temperatures appear to increase the speed of performance because they accelerate the body's "internal clock." Fox et al. (1967) showed that increase in body temperature accelerated people's perception of the passage of time. Colquhoun and Goldman (1972) investigated the ability of subjects to detect target stimuli against a noisy background at a temperature of 38^0 dry-bulb 33^0 wet-bulbs. It was found that only when work in the heat was accompanied by an actual increase in body temperature was an effect on performance observed. Azer et al. (1972) provide more evidence that hot conditions have significant effects on performance only when they cause a rise in body temperature. In their experiment performance decrements occurred when subjects worked at 35^0 C or 75relative humidity, but not at 35^0 or 37.5^0 and 50 percent relative humidity.

Assessment of heat stress exposure limits

Although heat acclimatization improves the capacity of the person to work under hot thermal conditions, the dangers and problems associated with exposure to heat stress cannot be totally relieved. Even for an acclimatized person, the maximum tolerable levels of heat exposure depend on the combination of ambient temperature, radiernt heat, humidity, air movement, metabolic heat during work, and the duration of exposure.

Factors Affecting Heat Stress And Strain

The following three general factors affect the level of heat stress of individuals who work in hot environments:

- **Environmental thermal conditions**: that is ambient temperature radiant heat, humidity and air movement.
- **Physical workload,** which positively affects the body's heat generated internally, through metabolism.
- **Clothing:** some clothes are permeable and allow heat exchange between the body and the surrounding environment. Others are impermeable, especially those used in

personal protective garments for use in chemically hazardous environments, which constrict the heat exchange process. Holzl et al. (1983) found that at 79^0F (26.1^0C) ET*, individuals with a clothing value of 0.54 clo, with no difference due to gender.

The threshold limit of heat stress should be modified to account for clothing. Clothing can be as unrestrictive as shorts and a T-shirt or as restrictive as a suit of armor. Restrictive clothing can interference with the body's evaporation capability. As Ramsey (1978) stated, for unrestrictive clothing, a positive 2^0C (3.6^0F)is added to the threshold limit. As much as 10^0C (18^0F) may be subtract from the heat stress TLVs to account for a suit of armor.

The level of heat strain experienced by an individual exposed to heat stress is influenced by the above three heat stress factors and the personal characteristics, such as gender, age, race, physical fitness, status of nutrition, medical history, skill, body build and heat acclimatization. These personal characteristics are described in the following section.

Perception of air and thermal quality

In the previous sections, individual differences in heat tolerance were noted. Individual differences in temperature preference also exist. Investigations have shown that some people find temperatures as low as 18^0C comfortable, whereas others prefer temperatures higher than 23^0C. Sundstrom (1986) suggests on the basis of findings such as these that individuals be given a certain amount of control of the temperature of their workplaces.

The threshold at which air is perceived as stuffy begins at a relative humidity of 60 percent at 24^0C and 80 percent at 18^0C. Dehumidifiers can be used to lower the relative humidity in a building to acceptable levels. Low relative humidity causes bodily secretions to dry up. Under these conditions, the occupants may complain of dry, blocked noses and eye irritation. Contact lens wearers may experience eye discomfort since proper adhesion of the lens to the eye depends on a continuous supply of lachrymal fluid to maintain a thin, moist film over the cornea. Somewhat counterintuitively, low relative humidity inside houses and offices can be a problem in cold, wet countries if artificially heated buildings are not ventilated adequately and if humidifiers are not provided.

Applications and Discussion

Temperature regulation in the human is normally maintained in a very close range, around 37^0C. As a worker is exposed to warm or cool environments, physiological changes take place to maintain the required body temperature. Through a process of acclimatization, the body adapts somewhat to the thermal load of the environment. However as the thermal load exceeds the body's ability to adapt, engineering and administrative controls or persona protective equipment must be incorporated to protect the worker.

There are many occupations in which workers are routinely exposed to hot and cold environments. If the worker is not properly protected the consequences could become fatal. This chapter has provided tools for understanding the thermal environment and physiological responses to change in temperature. The ergonomist should be able to assess a thermal environment, understand the exposure risks for workers and to develop guidelines for employees exposed to such environment.

Module 4. Rehabilitation scheme and DMR Act

Lesson 13. DANGEROUS MACHINES (REGULATION) ACT

13.1. Introduction

Traditional agriculture uses mainly human, animal and mechanical power. Human are also used to control and operate hand tools, self-propelled and power operated agricultural machines. Improper and careless use of agricultural machinery increases chance of casualties due to agricultural accidents. Threshers were introduced during seventies in Indian agriculture. Due to various benefits of threshers like saving in time, cost and human energy, the farmers adopted it to a very large extent. The newly introduced thrashers were basically designed for functional performance and the human safety aspects were lacking. This resulted in a large number of thresher accidents and many workers lost their lives/limbs. Verma *et al.* (1978) conducted a survey on thresher related accidents causing injuries in Punjab state and reported that about 73% of these were due to human factors, 13% due to machine factors and 14% due to crop and other factors. The survey also mentioned that 59% of the victims were hired labourers. Safe feeding devices for power threshers were designed and included in BIS standards. In 1983, the Govt. of India enacted the "Dangerous Machines (Regulation) Act-1983" (DMRA-1983) and made the safe feeding chutes/safe feeding system compulsory on power threshers (Anonymous, 2000).

13.2. Dangerous Machines (Regulation) Act - 1983

In 1983, the Parliament passed an act to provide for the regulation of trade and commerce in and production, supply, distribution and use of the product of any industry producing dangerous machines with a view to securing the welfare of labour operating any such machines and for payment of compensation for the death or bodily injury suffered by any labourers while operating any such machine, and for matters connected therewith or incidental thereto. Various sections of DMRA-1983 are listed in Table 13.1.

Table 13.1. List of various chapters and sections of DMRA-1983.

Section No.	Title
Chapter I - Preliminary	
1	Short title, extent and commencement
2	Declaration as to expediency of control by Union
3	Definitions
4	Act to override all other enactments

Chapter II – Administration of the act	
5	Appointment and functions of controller
6	Power of controller to issue orders
7	Appointment of Inspectors
8	Controller, etc., to be public servants
Chapter III – Issue, renewal and cancellation of licences to manufacturers and dealers	
9	Licensing of manufacturers and dealers
10	Suspension and cancellation of licences
11	Cancellation of licence on application by manufacture or dealer
12	Licence to a firm to be invalid on the change of partnership
Chapter IV – Duties and responsibilities of manufacturer or dealer of a dangerous machine	
13	Manufacturer to ensure that every part of a dangerous machine conforms to prescribed standards
14	Particulars to be specified on very dangerous machine
15	Duties of the manufacturer to supply operator's manual with each dangerous machine
16	Certificate and guarantee by manufacturers and dealers
17	Liability of the manufacturer for reimbursement
18	Manufacturers and dealers to maintain records
Chapter V – Duties and obligations of users of dangerous machine	
19	User to get each dangerous machine registered
20	Matters to be ensured by users
21	Modification of existing dangerous machine
22	Employer's liability for compensation
23	Notice of accident
24	Duty of employer to take out insurance policies
25	Omission or failure of the employer to take out insurance policies
Chapter VI – Inspection, search and seizure	

26	Examination of machine causing death or injury
27	Inspection of records etc.
28	Power to enter and search
29	Power of seizure
30	Search and seizure to be made in accordance with the code of “Criminal Procedure, 1973”
Chapter VII – Offence and their trial	
31	Punishment for contravention of the provisions of the Act
32	Offences by companies
33	Cognizance and trial of offences
Chapter VIII - Miscellaneous	
34	Appeals
35	Protection of action taken in good faith
36	Power of Central Government to make rules
37	Power of State Government to make rules
38	Power to give directions

13.2.1. Duties and responsibilities of manufacturers of dangerous machines

The salient points mentioned under chapter IV of the DMRA-1983 are:

Section No.	Title	Salient points
13	Manufacturer to ensure that every part of dangerous machine conforms to prescribed standards	Manufacturing a dangerous machine as per standards laid down by the Indian Standards Institution. Providing safety guards for prime mover, transmission machinery and every other dangerous part, such as, rollers, blowers, sieves, and elevator. Providing the machine with danger signals indicating the point beyond which no limb shall be inserted for the purpose of feeding the machine or for any other purpose.
14	Particulars to be specified on every dangerous machine	The direction of the rotation and the number of rotations per minute. Its power requirement and the name and address of the

		manufacturer, the year of its manufacture, and the date, number and other particulars of the licence of the manufacturer.
15	Duties of the manufacturer to supply operator's manual with each dangerous machine	Every manufacturer shall supply along with each dangerous machine a manual containing general instructions regarding the operation of such machine, and shall also include cautions.
16	Certificate and guarantee by manufacturers and dealers	Every manufacturer and dealer shall deliver a declaration to the effect that the machine conforms to the standards laid down by or under this Act and also complies with the provisions of this Act and the rules and orders made thereafter.

13.2.2. Duties and obligations of users of dangerous machines

The salient points mentioned under chapter V of the DMRA-1983 are:

Section No.	Title	Salient points
19	User to get each dangerous machine registered	No dangerous machine shall be operated until it has been registered.
20	Matters to be ensured by users	Such machine conforms to the standards. No child is employed for the operation of such machine. Adequate arrangements exist for rendering first aid to any person who may suffer any injury while operating such machine.
22	Employer's liability for compensation	If death or dismemberment of any limb or any other bodily injury is caused to operator, his employer shall be liable to pay compensation. The employer shall not be liable if injury does not result in disablement of the operator for a period exceeding three days; or is directly attributable to influence of any intoxicant or drug, or willful removal of any safety guard or other device by the worker.
24	Duty of employer to take out insurance policies	Every employer shall take out insurance policies to make payment of compensation to operator of a dangerous machine.

13.2.3. Offences and their trial

The salient points mentioned under chapter VII of the DMRA-1983 are:

Section No.	Title	Salient points
31	Punishment for contravention of the provisions of the Act	Imprisonment for a term which may extend to six months, or with fine which may extend to one thousand rupees

13.3. Changes suggested in DMRA-1983

In spite of passing of this act in 1983, it was adopted by some states only. As agriculture is a state subject, the implementation of this act is the prerogative of the state Govt. The agricultural machinery manufacturers were also not in favour of the act and demanded repeal of the same. Gite *et al.* (2006) suggested following modifications for better implementation of the act by the Government:

1. It is more appropriate if the Controller notified by the State Govt. is Agricultural Engineering/Agricultural Department official.
2. It is not practical for the users to get the threshers registered with the Controller due to various logistics problems. There should be registration at Panchayat level only. Also the procedure of registration needs to be simplified.
3. The manufacturer may provide first aid kit along with thresher itself.
4. The clause about employer's liability for compensation is not justified and therefore, needs to be modified. Compensation may be provided through State Agricultural Marketing Board as prevalent in Punjab, Haryana, Rajasthan, Gujarat and Uttar Pradesh.
5. The present system of giving notice of the accident creates disharmony in the rural society and needs to be modified. The Punjab pattern of reporting the accident to Agricultural Marketing Board is recommended.
6. The clause about duty of employer to take out insurance policies is not practical and needs to be modified.
7. The clause about omission or failure of employer to take out insurance policies is not justified and therefore, needs to be modified.
8. The examination of machine causing death or injury needs to be modified. The accident may be reported to Agricultural Marketing Board through local agricultural extension workers.

9. The clause on power of Inspector about seizure is difficult to implement and needs to be modified.

10. The clause about search and seizure procedure is difficult to implement and needs to be modified.

11. The provisions given in the clause about punishment for contravention of the act are unrealistic and needs modifications. The clause about imprisonment may be removed.

13.4. Dangerous Machines (Regulation) Rules-2007

DMRA-1983 was amended by Central Government in 2007. Apart from power thresher, as mentioned earlier, power operated chaff cutter and sugarcane crushers were also added in the list of dangerous machines. A list of BIS standards were given for compliance in case of each of dangerous machines, as under:

Sr. No.	Dangerous machine	BIS standards for compliance
1	Power thresher	IS 9020: 2002 (Power threshers – safety requirements)
2	Power operated chaff cutter	IS 15542: 2005 (Power operated chaff cutter – safety requirements) IS11459: 1985 (Specifications for power operated chaff cutter)
3	Sugarcane crusher	IS 15561 : 2005 (Sugarcane crushers – safety requirements) IS 1973: 1999(Sugarcane crushers - specifications)

Lesson 14. REHABILITATION AND COMPENSATION TO AGRICULTURAL ACCIDENT VICTIMS

14.1. Introduction

Agriculture is the mainstay of Indian economy and it contributes nearly 17 per cent of Gross Domestic Product (GDP). About sixty percent of Indian population is dependent on agriculture for their livelihood. In India, the numbers of cultivators are about 12.73 crores alongwith 10.68 crores agricultural labourers. More changes have occurred in agriculture during the last five decades and increasing use of farm machinery is one of the examples. Farm mechanization alongwith increased application of other agricultural inputs such as seeds, pump sets, fertilizers, pesticides, etc. have enhanced the productivity and production on the farms. But on the other hand accidents and causalities in the agricultural sector have increased tremendously. A number of steps including legislations were taken with the objective to reduce agriculture related accidents and rehabilitation of victims and their family members. These legislative actions included:

- BIS standards for safety aspects of various agricultural machines,
- Dangerous Machines (Regulation) Act,
- Rehabilitation and compensation to agricultural accident victims.

14.2. Rehabilitation scheme for agricultural accident victims

Most of the workers in Indian agriculture are in unorganized sector and, therefore, accidents and safety don't get due importance either at farm level or at organizational level. Though nationwide efforts are being made to reduce accidents, yet it is not possible to totally eliminate them. The majority of agricultural accidents are due to human factors viz. lack of awareness, lack of formal training, long working hours, restlessness, carelessness, fatigue, seasonal operations of agriculture, etc. Therefore, monetary relief for rehabilitation of agricultural accidents victims and their family members is justified beyond doubt. In 1983, the Indian Parliament passed DMRA to regulate dangerous machines with a view to securing the welfare of operator and for payment of compensation for the death or bodily injury suffered by any labourers while operating such machines. As per DMRA, the manufacturer was fixed responsibility for providing compensation to user in case of accidents due to manufacturing fault. The employer was also asked to take accident insurance policy for users. Further, this act covered only the power threshers and its implementation was lacking in different states of India.

Punjab State took a lead for rehabilitation of accident victims by providing blanket insurance coverage to all concerned engaged in agriculture and marketing operations at any time during the year. This social welfare scheme has been widely appreciated all over the country and some other states have also adopted similar schemes.

14.2.1. Rehabilitation scheme for agricultural accidents victims – Punjab Model

Compensation policy was formulated and proposal was submitted way back in 1978 and monetary aid was started in 1984 through Punjab State Marketing Board.

14.2.1.1. Basic policy

The Government of Punjab through Punjab State Marketing Board formulated policy and procedural rules for providing monetary relief for rehabilitation of agricultural accidents victims. It defined in detail the various terms and procedures for the effective implementation of policy. Among the various rules and regulations, it also formulated a quantitative percentage of loss of earning capacity depending upon the injury (Table 14.1).

Table 14.1. Loss of earning capacity depending upon injury.

S.N.	Description of injury	Loss of earning capacity (%)
1.	Loss of both hands or amputation at higher sites	100
2.	Loss of a hand and a foot	100
3.	Double amputation through leg or amputation through leg on one side and loss of other foot	100
4.	Loss of sight such that victim is unable to perform any work	100
5.	Very severe facial disfigurement	100
6.	Absolute deafness	100
7.	Amputation of upper or lower limbs depending upon its extent	10 - 45
8.	Loss of one eye or its vision depending upon its extent	15 - 20
9.	Loss of finger or its parts depending upon its extent	1 - 7

Punjab State Marketing Board provides financial help to all the farmers, their family members, agricultural labourers and marketing committee workers, while:

- Working on agricultural machinery and implements like threshers, tractor, trolleys, chaff cutters, spray pumps, etc. in field.
- Digging of wells or electrocution while operating tube wells on the farm.
- Using pesticides or due to snake bite in the field.
- Use of agricultural implements in the notified market committees in the state of Punjab.

- All accidents happening during agricultural operations in field or at farm house or in registered marketing committee or during transportation of agricultural produce to marketing committee.

Insurance scheme was started with collaboration of Insurance Company for coverage of accidents leading to death or disablement to agricultural workers. At the start, the policy was named as 'Compensation in case of thresher accidents' and covered only threshers and chaff cutter. However, later on other agricultural accidents as stated above and also due to crop produce or lightening, etc. were included to cover the gaps. Punjab State Marketing Board is, thus, covering about 21 lakhs cultivators, 15 lakh agricultural labourers and also the family members of the cultivators in the Punjab state.

14.2.1.2. Economics involved in monetary relief

No insurance premium is collected from anyone covered under the rehabilitation scheme. In fact, Punjab State Marketing Board has 145 principal (regulated) agricultural market committees and a large number of notified committees for facilitating sale and purchase of agricultural produce. A fee @ 2% is collected for providing facilities for sale, purchase, storage and processing of agricultural produce. The collected fee amounts to over 300 crores at present. The fund collected is spent on various development schemes for the social welfare of the farmers and rural mass. The rehabilitation of victims of agricultural accidents is one of these schemes. A budget of 5-10 lakhs is allocated to each of the principal committee to speed up the relief to victims. The monetary relief at the start was fixed at Rs. 12,000/- in case of loss of life and was revised regularly to the maximum of Rs. 2,00,000/- at present. The monetary compensation amount in case of loss of limb was also revised accordingly. Also a new category of type of injury has been introduced in the year 2011. Monetary compensation is also provided to the victims of agricultural accidents who suffer internal injuries leading to disability (more than 25%) of body parts (Table 14.2).

Table 14.2. Rates of monetary compensation by Punjab State Marketing Board

Type of injury	Rate of monetary compensation (Rs.) w.e.f.					
	1.4.1984	1.4.1989	1.4.1996	1.4.2001	1.11.2007	29.03.2011
Loss of life	12,000	30,000	50,000	75,000	1,00,000	2,00,000
Loss of one limb i.e. hand, arm, leg, foot etc./ any other equivalent serious injury	5,000	12,000	20,000	30,000	40,000	40,000
Loss of two limbs i.e. hands, arms, legs, eyes, feet etc./ any other equivalent serious injury	7,000	20,000	30,000	45,000	60,000	60,000
Loss of finger/ finger parts equivalent to amputation of	1,000	3,000	5,000	7,500	10,000	10,000

complete one finger.						
Loss of four fingers i.e. equivalent to amputation of one body part.	5,000	12,000	20,000	30,000	40,000	40,000
Disability (>25%) of body parts	-	-	-	-	-	50,000-1,00,000

No budget limit is fixed for providing monetary relief to victims of Punjab state. In fact, all the genuine victims are provided relief as per recommended rate. About 1600 agricultural accidents victims of Punjab state were provided with the monetary relief during the recent time (Table 14.3). The amount of relief disbursed under this rehabilitation scheme was about eight crores annually.

Table 14.3. Monetary relief by Punjab State Marketing Board

Financial year	Number of victims	Amount disbursed (Rs. in crores)
1998-1999	1438	2.51
1999-2000	1407	2.39
2000-2001	1539	2.37
2001-2002	1878	4.84
2002-2003	1750	5.04
2003-2004	1663	5.07
2004-2005	1830	5.16
2005-2006	1778	6.31
2006-2007	1818	5.83
2007-2008	1869	6.46
2008-2009	1902	7.39
2009-2010	1946	8.43
2010-2011	1934	8.67
2011-2012	1612	7.89

14.2.1.3. Application procedure

The victim, or the nearest successor in case of loss of life to victim, has to report in written about the accident to the nearest market committee office within 30 days of accident and submit duly verified prescribed application alongwith supporting documents immediately afterwards. The performa includes personal details of the victim, details of accident, nature and extent of injury, medical treatment, etc. The victim or family member has to submit a police report and a medical report. Death certificate needs to be enclosed in case of loss of life. The victim has to submit an affidavit certifying that monetary relief is not being sought from any other agency.

The application and necessary documents after being received in the office are verified confidentially by a three member committee consisting of i) Administrator or Chairman of the market committee, ii) Secretary of market committee, and iii) Assistant or Deputy District Mandi Officer. The monetary aid, after due approval, is distributed among victims at the earliest and without delay in the presence of some reputed persons of the area or competent officials of Marketing Board.

14.3. Status of rehabilitation scheme for agricultural accident victims in India

The Punjab State Govt. took a lead in formulating and implementing monetary compensation scheme for rehabilitation of agricultural accidents victims and their family members. The procedures and amount were revised as per need of time and various legal issues. Some other Indian States followed the Punjab Model and started providing monetary compensation to accident victims. A list of States providing monetary compensation is as given in Table 14.4.

Table 14.4. Rate of monetary compensation in case of death of victims.

Sr. No.	State	Nodal agency	Monetary compensation in case of death (Rs.)
1	Haryana	Haryana Marketing Board	50,000/-
2	Karnataka	Karnataka State Agricultural Marketing Board	50,000/-
3	Punjab	Punjab State Marketing Board	2,00,000/-
4	Rajasthan	Rajasthan State Agricultural Marketing Board	1,00,000/-
5	Uttar Pradesh	State Agricultural Produce Marketing Board	50,000/-

Similar procedure should be adopted all over the country, so that agricultural accidents victims may be rehabilitated. The amount of monetary relief also needs to be increased from the present level.